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Economy: strategy and practice is a double-blind peer-reviewed journal dedicated to publishing high-quality articles on economics, economic development, strategic policy and practical solutions. The three words in the title of the journal “economics”, “strategy” and “practice” are key to the journal’s vision. The journal provides an international platform for interdisciplinary research that integrates economic theory, policy analysis, and practical applications. It seeks to contribute to global academic discourse by addressing contemporary challenges related to sustainable development, digital transformation, and socio-economic resilience. The journal aims to advance theoretical and empirical research and to promote evidence-based policy analysis and practical solutions in the context of economic development at national, regional, and global levels.

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Remittances and Economic Growth in the Turkic Republics and Tajikistan: A Panel Data Analysis

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ABSTRACT

Migrant remittances are an important source of external financing for developing economies, but their impact on economic growth remains ambiguous. This study aims to examine the long-run effects of remittances, foreign direct investment (FDI), trade openness, and tax revenues on real GDP and to identify causal relationships among these variables in five Turkic Republics (Azerbaijan, Kazakhstan, Kyrgyzstan, Türkiye, and Uzbekistan) and Tajikistan over the period 2005–2023. The analysis employed tests of cross-country dependence and coefficient homogeneity, panel unit root tests, the Durbin–Hausman cointegration test, FMOLS and DOLS estimates, as well as the Dumitrescu–Hurlin panel causality test. The results showed a positive long-term relationship between remittances and real GDP: the coefficient was 10.7917 for FMOLS ($p = 0.0137$) and 3.8556 for DOLS ($p = 0.023$). Trade openness also has a positive and statistically significant long-term relationship with real GDP: the corresponding coefficients were 1.1260 and 1.2183 ($p = 0.000$ in both cases). At the same time, the coefficients for foreign direct investment turned out to be negative: -1.7361 for FMOLS ($p = 0.051$) and -2.2875 for DOLS ($p = 0.088$). The results obtained confirm the significant role of remittances in the economic dynamics of the countries under study and indicate the feasibility of improving the mechanisms for attracting them into the formal financial sector and for their productive use. The findings underscore the need to develop formal financial channels, improve the efficiency of using money transfers, and direct external financial flows toward productive investments and sustainable economic growth.

KEYWORDS: Economy, Economic Growth, Trade Openness, Financial Integration, External Financing, Intercountry Dependence, Turkic Republic, Tajikistan

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Денежные переводы и экономический рост в тюркских республиках и Таджикистане: панельный анализ

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АННОТАЦИЯ

Денежные переводы мигрантов являются важным источником внешнего финансирования для развивающихся экономик, однако их влияние на экономический рост остается неоднозначным. Цель исследования заключается в оценке долгосрочного влияния денежных переводов, прямых иностранных инвестиций, открытости торговли и налоговых доходов на реальный ВВП, а также в выявлении причинно-следственных связей между этими переменными в пяти тюркских республиках (Азербайджане, Казахстане, Кыргызстане, Турции и Узбекистане) и Таджикистане за период 2005–2023 гг. Для анализа применены тесты межстрановой зависимости и однородности коэффициентов, панельные тесты единичного корня, тест коинтеграции Дурбина–Хаусмана, оценки FMOLS и DOLS, а также тест панельной причинности Думитреску–Хёрлина. Результаты показали положительную долгосрочную связь денежных переводов с реальным ВВП: коэффициент составил 10,7917 по FMOLS ($p = 0,0137$) и 3,8556 по DOLS ($p = 0,023$). Открытость торговли также имеет положительную и статистически значимую долгосрочную связь с реальным ВВП: соответствующие коэффициенты составили 1,1260 и 1,2183 ($p = 0,000$ в обоих случаях). В то же время коэффициенты прямых иностранных инвестиций оказались отрицательными: –1,7361 по FMOLS ($p = 0,051$) и –2,2875 по DOLS ($p = 0,088$). Полученные результаты подтверждают значимую роль денежных переводов в экономической динамике исследуемых стран и указывают на целесообразность совершенствования механизмов их привлечения в формальный финансовый сектор и направления продуктивного использования. Результаты подчеркивают необходимость развития формальных финансовых каналов, повышения эффективности использования денежных переводов и ориентации внешних финансовых потоков на производительные инвестиции и устойчивый экономический рост.

КЛЮЧЕВЫЕ СЛОВА: экономика, экономический рост, торговая открытость, финансовая интеграция, внешнее финансирование, межстрановая зависимость, тюркская республика, Таджикистан

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INTRODUCTION

In 2024, the approximate number of international migrants is 304 million individuals. Despite the rise in foreign migrants, this proportion has remained consistently at 3.7% of the global population for many years. In other words, almost 4 out of every 100 individuals who reside are international migrants. According to the World Economic Forum's Global Risks Report, involuntary migration or relocation is among the top 10 short-term challenges (WEF, 2025). The primary solutions offered for mitigating this risk factor are augmenting development funding and establishing international agreements (WEF, 2025).

Remittances from migrants departing their homes to pursue economic opportunities are crucial for both households and the broader economies of developing nations. Remittances enhance population resilience, facilitating the attainment of Sustainable Development Goals 11, 13, and 16, despite financial or social upheaval in the home country (Ullah et al., 2025). Analysis of the influence of migrants on the public finances of their host nations reveals that migrants contribute more to the public budget through taxation than they receive from social security, healthcare, and educational expenses (OECD, 2021). Immigrants' contributions to the public budget are indispensable; once they reach a certain threshold, they can finance all congestible public goods. Furthermore, they substantially support the funding of all public goods, including public debt and national defense, thereby enhancing the public finances of their host countries (OECD, 2021).

In 2023 and 2024, remittances to low- and middle-income nations surpassed the combined total of foreign direct investment and official development assistance, reaching 636 billion and 699.9 billion dollars, respectively. Due to the robust economies of nations employing migrants, remittances have consistently increased throughout pandemics and worldwide financial crises (Ratha et al., 2024; UN, 2026). Research indicates that the economic and political circumstances of the country do not significantly influence the remittances provided by workers (Ambrosius et al., 2021). Despite an unparalleled worldwide recession during the COVID-19 pandemic, remittances continued to rise. The current consensus is that travel limitations

have shifted remittances from informal to formal routes (Kpodar et al., 2023). The use of unofficial channels for transmitting worker remittances to the home country complicates the assessment of their economic impact, while alternative transfer systems, such as “hawala”, which operate without legal regulation, raise concerns about money laundering and terrorist financing (Kholmatova, 2024). The World Bank's strategy to promote worker remittances in accordance with the SDGs is to increase remittance volumes by lowering transfer costs. The World Bank has introduced an online tool to compare global remittance costs and promote transparency in international money transfers. Reducing remittance transfer costs to less than 3% by 2030, in line with SDG 10, could encourage the use of formal remittance channels (Mohammed, 2025; Thakur et al., 2026).

The correlation between remittances and real GDP is affected by financial sector development, economic openness, the purpose of remittances (investment or consumption), their share of GDP, and the country's income level (low, middle, or high) (Radic et al., 2023). In middle-income countries with a relatively strong financial system, remittances have a positive effect on growth (Aggarwal et al., 2011). However, this effect is not seen in low-income countries with a weak financial system. This circumstance suggests that the crucial factor in the influence of remittances on economic growth is the efficient operation of the financial system, channeling cash from official sources to productive investments (Sholehah & Samputra, 2025). Recent studies contend that substantial remittance inflows, contingent upon their utilization (investment versus consumption), may induce a production shift toward sectors with inherently weaker long-term development potential, a phenomenon referred to as “Dutch disease” (Manato, 2025; Behzadan & Chisik, 2025).

For the past two decades, the proportion of worker remittances to GDP in Kyrgyzstan and Tajikistan has consistently been above 20%, with Tajikistan ranking among the highest globally in this regard, almost reaching 50% (World Bank, 2025). Due to the elevated rate of labour migration from the Turkic republics and Tajikistan, substantial sums of foreign cash are remitted to these nations (Sugözü & Talantbekova, 2024).

Alongside conventional macro- and

microeconomic determinants of economic growth, scholars increasingly focus on the strategic significance of FDI and remittances in fostering sustainable development in Türkiye, the Turkic republics, and Tajikistan. Remittances substantially influence the stability of domestic demand in Tajikistan (UN, 2026). This study aims to examine the long-run effects of remittances, foreign direct investment (FDI), trade openness, and tax revenues on real GDP and to identify causal relationships among these variables in five Turkic Republics (Azerbaijan, Kazakhstan, Kyrgyzstan, Türkiye, and Uzbekistan) and Tajikistan over the period 2005–2023. The study seeks to elucidate the long-term cointegration relationship and the direction of causation among the variables, accounting for cross-sectional dependence and slope heterogeneity within a complex framework characterised by varying degrees of integration among the series. Thus, despite the large literature on remittances and economic growth, empirical evidence for the Turkic Republics and Tajikistan is scarce, especially when accounting simultaneously for cross-sectional dependence, country heterogeneity, fiscal variables and multiple external sources of financing. Using second-generation panel econometric techniques that account for cross-sectional dependence and heterogeneity across countries, the study fills these gaps by analyzing the joint effect of worker remittances, foreign direct investment, trade openness, and tax revenues on economic growth. It does so by providing stronger empirical evidence on the impact of external finance inflows and fiscal considerations in enabling sustainable economic growth in the selected economies.

LITERATURE REVIEW

The empirical research on the macro-financial effects of international capital flows shows considerable disagreement over the growth-enhancing capacity of migrant remittances and foreign investments. The scholarly discussion is not offering consensus but, rather, is divided into subject clusters based on operational channels, the structural maturity of recipient economies, and possible crowding-out issues. The consensus view in the empirical research is that remittance inflows are an important external source of finance that reduces credit limits and promotes long-run

economic growth, especially in areas with financial friction. The basic mechanism of this optimism is that migrant remittances operate as a parallel credit link financing household spending, accumulation of domestic savings, and micro-entrepreneurship when formal banking institutions are inadequate.

Giuliano and Ruiz-Arranz (2009) have shown in a broad panel setting of 100 developing countries that remittances are very efficient in boosting economic performance exactly where the formal banking sector is not well developed, acting as an institutional substitute for credit markets. For example, Aggarwal et al. (2011) present robust evidence in favour of this financial deepening view, using a GMM framework across 109 developing countries and confirming a positive relationship between remittance receipts and banking sector development variables, such as domestic deposit and loan ratios.

The analysis of transition and post-Soviet regions reveals positive growth paths that align perfectly with the geographic focus of this study. For example, Abduvaliev and Bustillo (2020) assessed 10 post-Soviet states. They proved that a 1% increase in remittance inflows leads to a 0.25% growth in GDP per capita, while concurrently reaching a 2% decrease in poverty measures. Similarly, Kumar et al. (2018) applied ARDL bounds testing for Kyrgyzstan and Macedonia and found remittances to be a consistent catalyst for long-term real production growth. Recent studies by Khan (2025) and Pal et al. (2022) have noted that these inflows have persistent positive effects on aggregate social welfare, reduce income inequality, and strengthen economic development provided that the funds are directed to human capital formation, e.g., education and healthcare infrastructure.

The second group of literature presents a more complex perspective. It argues that the growth dividend from external capital is neither automatic nor unconditional. Instead, it is fully contingent upon the institutional environment, financial literacy, and the overall absorptive capacity of the home country. This body of research highlights the importance of formal financial inclusion as a crucial intermediary or regulatory channel that transforms raw foreign currency liquidity into productive local assets.

In this context, Edafe et al. (2024) investigated the relationship between remittance channels

and formal banking infrastructure in Nigeria, revealing that the effectiveness of formal payment systems and specialised remittance-related banking products is crucial for fostering inclusive growth. Khan et al. (2025) further develop this analysis across 79 developing countries, illustrating that in environments characterized by high financial inclusion, incoming remittances are more likely to be invested in entrepreneurial activities rather than used solely for immediate consumption.

Moreover, the structural link of these inflows with public finance is an important but understudied issue. Bangaké et al. (2025) studied the endogeneity of migrant transfers and public budgets for 83 developing nations. Their dynamic panel threshold regressions found that the tax revenue-raising potential of remittances is very sensitive to institutional threshold factors, such as control of corruption and contraction of the informal economy. In a country-specific context, Özyakışır et al. (2024) verified that concerning Türkiye, remittance inflows impact domestic financial development asymmetrically, supporting the policy mandate of preserving robust pension and social security linkages for the diaspora to retain foreign exchange within the formal banking architecture.

On the other hand, the third group of literature warns against over-reliance on inflows of external capital and paints a more negative macroeconomic narrative, characterised by structural bottlenecks, substitution of labour and the phenomenon of 'Dutch disease'. The pessimistic approach asserts that uncoordinated and large foreign cash windfalls can result in actual exchange rate distortions,

decrease the international competitiveness of manufacturing sectors, and unwittingly breed political complacency.

Barajas et al. (2009) made a comprehensive methodological critique of traditional growth models based on fixed-effects analysis across 84 countries, finding no statistically significant positive economic benefits of remittances. In their study of Kazakhstan, Kaliyeva et al. (2026) found a short-term positive relationship between income and migration attractiveness ($p < 0.001$), but no long-term stable cointegration. Institutional conditions and infrastructure are the determining factors. The growth-neutral or even negative effect was expressly ascribed to behavioural changes, such as the substitution of labour for leisure, and the structural camouflage that remittance buffers provide to short-sighted governments. This structural disconnection is very apparent in resource-dependent environments. Gachino (2025) used Augmented Mean Group (hereinafter – AMG) and panel VAR estimators for the leading economies in Africa and found an uncoordinated dichotomy. FDI directly financed capital accumulation, while remittances had a persistent negative association with long-term growth because of their severe consumption-driven orientation.

Table 1 demonstrates that the international literature conceptualizes external financial inflows and migrant transfers along three primary theoretical axes: a direct liquidity-enhancing growth mechanism, an institutional/financial mediation requirement, and the risk of Dutch Disease distortions.

Table 1. Literature review matrix

Thematic axis/channel	Author(s)/year	Main findings
The Liquidity-Enhancing and Financial Inclusion Channel	Giuliano & Ruiz-Arranz (2009), Aggarwal et al. (2011), Kumar et al. (2018), Abduvaliev & Bustillo (2020), Sugözü & Talantbekova (2024), Khan (2025)	Remittances positively affect growth.
Absorptive Capacity, Institutional Quality and Complementarity Channel	Özyakışır et al. (2024), Edafe et al. (2024), Bangaké et al. (2025), Khan et al. (2025), Kaliyeva et al. (2026)	Remittances moderately or conditionally affect growth.
Crowding-out risks and “Dutch Disease” Dynamics	Barajas et al. (2009), Gachino (2025), Manato (2025), Behzadan & Chisik (2025), Gajurel & Chindengwiwe (2025)	Remittances negatively or neutrally affect growth.

Note: compiled by the authors

This empirical matrix provides a comprehensive theoretical baseline to rationalize the econometric findings obtained for the selected 5 Turkic Republics and Tajikistan. When all the studies are synthesized, the empirical literature indicates that the growth effects of remittances are extremely situation-specific rather than generally positive or negative. The benefits of remittance inflows through investment and human capital accumulation are generally associated with countries with developed financial systems and stronger institutions, but the growth effects can be limited, or even Dutch disease dynamics may be at play for economies with poor institutional quality or excessive consumption-oriented use of remittances. The divergence in results suggests that institutional capacity is an important determinant of the ability to convert external financial flows into sustained economic growth.

Modern macroeconomic models, both empirically and theoretically, confirm the risk of unbalanced, consumption-led growth, popularly known as “remittance-induced Dutch disease”. Massive, non-intermediated cash injections by migrants result in a harmful reallocation of local production factors towards non-tradable sectors with fundamentally weak long-term productivity and low technological diffusion, as confirmed by investigations by Manato (2025) and Behzadan and Chisik (2025). Gajurel and Chindengwike (2025) similarly warn that ignoring domestic industrial productivity and passively relying on external currency inflows instead upsets the economic balance and requires the creation of institutional “remittance banks” to direct incoming liquidity into physical capital formation artificially.

The prior studies generally show ambiguous growth benefits of remittances and foreign direct investment. These disparities appear mainly to be due to differences in institutional quality, financial development, nation characteristics, and estimating methodology. Therefore, the literature increasingly points out that the efficiency of foreign financial inflows is a function of the economic structure and policy environment of receiving nations, rather than a universal growth mechanism. This result suggests that additional research in comparatively understudied countries such as the Turkic Republics and Tajikistan is warranted.

Previous studies have either analysed individual

countries (Abdulai, 2023; Edafe et al., 2024; Özyakışır et al., 2024), focused on groups of developing countries (Khan et al., 2025; Barajas et al., 2009; Aggarwal et al., 2011), or examined a limited subset of Central Asian countries (Sugözü & Talantbekova, 2024; Koc et al., 2024). However, relatively few studies have jointly examined the Turkic Republics and Tajikistan as a distinct group of economies. Moreover, many previous studies employ first-generation methods (Siddique et al., 2012; Pal et al., 2022) that do not account for cross-sectional dependence arising from common policy patterns or global shocks, or for structural heterogeneity across countries. This analysis addresses the literature gap by applying second-generation panel unit root tests (CADF and CIPS), long-run estimators (FMOLS and DOLS), and the Dumitrescu–Hurlin panel causality test. This study is an innovative research endeavor that integrates worker remittances, foreign direct investment, trade openness, and tax revenues into a singular dynamic model tailored for the Turkic Republics and Tajikistan. It addresses econometric issues stemming from differing levels of series integration by employing second-generation methodologies. It empirically illustrates the impact of remittances on GDP, both directly and indirectly through fiscal policies.

RESEARCH DESIGN

This section provides a systematic summary of the empirical methodologies employed and explains how the hypothesis concerning the impact of remittances on real GDP in the chosen countries is tested. This section explicitly clarifies the properties of the data employed, the time span of the search, the variable composition, and the motivation for using econometric methodologies. To study the relation between real gross domestic product, remittances, trade openness, tax revenues, and FDI in the case of 5 Turkic Republics (Azerbaijan, Kazakhstan, Kyrgyzstan, Türkiye, and Uzbekistan) and Tajikistan, we have analyzed a panel model for the period between 2005 and 2023. Due to data limitations during the specified period, Turkmenistan could not be included in the study. Table 2 presents the variables employed in the model specification.

Table 2. Description of variables

Variable	Symbol	Description	Source
Real GDP	RGDP	Real gross domestic product (constant 2015 US\$)	World Bank and IMF
Remittances	REMIT	Personal remittances comprise personal transfers and employee compensation.	World Development Indicators
Trade openness	TRADE	As the ratio of imports plus exports	World Bank and IMF
Foreign direct investment	FDI	FDI refers to direct investment equity flows in the reporting economy.	World Bank and IMF
Tax revenues	TAX	Tax revenues	World Bank and IMF

Note: compiled by the authors based on the World Bank (2025) and IMF (2025)

Based on the theoretical and empirical literature, real GDP is assumed to depend on remittances, foreign direct investment, trade openness, and tax revenues. The model used for the current study, for the variables, is as follows in equation (1):

$$RGDP_{it} = \alpha_0 + \beta_1 REMIT_{it} + \beta_2 FDI_{it} + \beta_3 TRADE_{it} + \beta_4 TAX_{it} + \varepsilon_{it} \quad (1)$$

where:

$t = 1, 2, \dots, T$ – time-series index;

$i = 1, \dots, N$ – cross-sectional units;

$\beta_1, \beta_2, \beta_3, \beta_4$ – estimated coefficients of the explanatory variables;

α_0 – intercept;

ε_{it} – stochastic error term;

$RGDP_{it}$ – denotes the real gross domestic product;

$REMIT_{it}$ – the personal remittances comprise personal transfers and employee compensation;

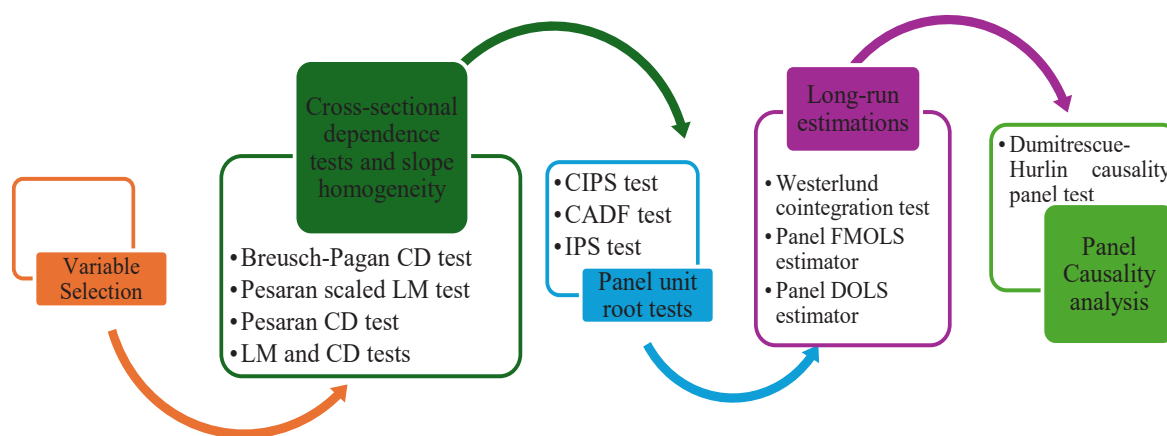
$TRADE_{it}$ – as the ratio of imports plus exports;

FDI_{it} – refers to direct investment equity flows in the reporting economy;

TAX_{it} – the government tax revenues.

To construct the panel data model, information for Azerbaijan, Kazakhstan, Kyrgyzstan, Türkiye, Uzbekistan, and Tajikistan was collected from World Bank and IMF databases. Also, panel data sets are data structures that contain time-series and cross-sectional records. This combination allows for observing changes over time while also registering differences among units. The panel data method improves prediction accuracy, increases degrees of freedom, and helps address multicollinearity by using a larger number of observations and variation. In addition, it allows for controlling for effects specific to different units of analysis. It also enables the modeling of changing behaviors, which increases the explanatory power of empirical studies.

The empirical methodology employed in this study is illustrated in Figure 1.

**Figure 1.** Methodology structure of the study

In econometric analyses of country-level panel data, cross-sectional dependence and heterogeneity may pose important methodological concerns. Hence, it is crucial to carefully assess these issues before determining the appropriate estimation strategy. The presence of common factors influencing the results, along with cross-sectional dependence and unit heterogeneity, may lead to biased estimates and weaken the robustness of empirical findings. Therefore, when these problems are present, the application of second-generation econometric methods becomes necessary.

The analysis initially investigates the presence of interdependence among panel units, which may stem from similar policy practices, external shocks, or unobserved common factors. To detect cross-sectional dependence, the Pesaran CD, Breusch–Pagan LM, Pesaran-scaled LM, and bias-corrected LM tests are employed. Using several complementary tests provides a more robust assessment of cross-sectional dependence. Identifying cross-sectional dependence is important because it guides the selection of appropriate panel unit root tests in the subsequent analysis. Cross-sectional dependence refers to the condition in which the error terms of the estimated models for each unit in the panel dataset are correlated, indicating a relationship among error terms from different units within the dataset (Kumari & Singh, 2025; Yerdelen Tatoğlu, 2017).

Following the identification of cross-sectional dependence, it is essential to assess the slope homogeneity of the dataset to determine which unit root test to use. Ensuring the reliability of estimation results requires addressing slope heterogeneity. In panel data analysis, slope heterogeneity refers to different responses among the units under investigation (such as countries, companies, individuals, etc.), both among themselves and over time, indicating distinct dynamics (Pesaran & Yamagata, 2008).

Two critical factors for selecting methods in panel data analysis are cross-sectional dependence and heterogeneity. The existence of cross-sectional dependency, indicating the correlation of error terms among units in the panel data set, dictates the appropriate unit root test to employ. First-generation unit root tests are recommended in the absence of cross-sectional dependence among the units, but

second-generation unit root tests are employed when such dependence is present (Kumari & Singh, 2025). This study employed second-generation unit root testing, specifically CADF, CIPS, and IPS. Spurious regression may arise while analyzing series that have a unit root (Alatrash et al., 2025). Therefore, it is important to determine the existence of a unit root.

The condition of heterogeneity, indicating that variable coefficients in the model differ between units or time, is crucial, as it dictates the selection of the estimate method employed. The simultaneous presence of cross-sectional dependency and heterogeneity plays an important role in selecting which causality tests to use. In addition, to determine the appropriate causality test for the study, it is essential first to identify the cross-sectional dependence of the panel dataset (Dritsaki & Dritsaki, 2020).

After unit root testing, the study examined variable cointegration. The Durbin–Hausman panel cointegration test, established by Westerlund (2008), is used to assess the presence of a long-term cointegration relationship in panel data models where the variables exhibit varying integration orders. The test is crucial in literature, particularly for yielding accurate findings in mixed integration frameworks where certain series are $I(0)$ and others are $I(1)$. The methodology employs the Durbin–Hausman approach within the error correction model, yielding two distinct test statistics: the panel statistic and the group statistic. The null hypothesis posits the absence of a cointegration relationship. In this regard, the test is sometimes favored as an alternative to conventional panel cointegration tests because of its comparatively flexible framework concerning cross-sectional dependence and its accommodation of varying integration orders. Following the cointegration analysis, long-term coefficients were estimated by the FMOLS and DOLS estimators.

In the presence of the situations mentioned above (the existence of cross-sectional dependence and heterogeneity), the Dumitrescu–Hurlin panel causality test in heterogeneous panels developed by Dumitrescu and Hurlin (2012) can be used.

The regression proposed by Dumitrescu and Hurlin (2012) for identifying causality in panel data is as follows in equation (2):

$$y_{i,t} = \alpha_i + \sum_{k=1}^K \gamma_i y_{i,t-k} + \sum_{k=1}^K \beta_i x_{i,t-k} + \varepsilon_{i,t} \text{ with } i = 1, \dots, N \text{ and } t = 1, \dots, T \quad (2)$$

where:

$y_{i,t}$ and $x_{i,t-k}$ – two stationary variables for every individual country in periods;

β_i – estimated coefficients of the explanatory variables;

α_i – intercept;

ε_{it} – stochastic error term.

The null hypothesis of the test in equation (2) is that there is no causal relationship in the panel dataset for which the variable x Granger causes y . The Dumitrescu and Hurlin test presumes that causality may exist for some units, but not necessarily for all. The Dumitrescu-Hurlin (2012) panel causality test is a strong alternative in panel data analysis because of its considerable advantages. The main advantage of this test is that it can give good results even with unbalanced panels. It also yields stronger inferences by accounting for cross-sectional dependence and correlation across units. Furthermore, it allows the

model to flexibly adjust to the data structure by identifying the ideal lag length for each variable independently in autoregressive processes.

RESULTS

This study explores the causality between real GDP, remittances, trade openness, foreign direct investment, and tax revenues by using the Dumitrescu-Hurlin (2012) panel causality test. The test starts by determining the existence of cross-sectional dependence through four widely utilized tests: the Breusch-Pagan LM test, the Pesaran scaled LM test, the Bias-corrected scaled LM test, and the Pesaran CD test. The presence of cross-sectional dependence is critical for identifying which tests to use in the study. This means there is a correlation between the error terms obtained from each unit in the panel dataset. Additionally, a shock in any country in the panel will clearly affect the others. The results of all these tests, as shown in Table 3, consistently indicate significant evidence against the null hypothesis of cross-sectional independence at the 1% level.

Table 3. Cross-sectional dependence test results for every variable

Test/Variables	RGDP	REMIT	TRADE	FDI	TAX
Breusch-Pagan LM	206.4691* (0.0000)	124.5082* (0.0000)	198.6532* (0.0000)	54.09779* (0.0000)	161.9215* (0.0000)
Pesaran scaled LM	34.95732* (0.0000)	19.99337* (0.0000)	33.53034* (0.0000)	7.138246* (0.0000)	26.82407* (0.0000)
Bias-corrected scaled LM	34.79065* (0.000)	19.82670* (0.000)	33.36367* (0.000)	6.971580* (0.0000)	26.65740* (0.000)
Pesaran CD	14.30439* (0.0000)	4.826467* (0.0000)	14.02616* (0.0000)	2.694330* (0.0071)	12.37112* (0.0000)
The values enclosed in parentheses within the table denote probability values. *Denotes significance at the 1% level of significance.					

Note: compiled by the authors

Before applying the causality analysis, it is essential to perform both cross-sectional dependence and heterogeneity analysis of the model. The model

in equation (1) is displayed in Table 4 as the result of slope homogeneity.

Table 4. Slope homogeneity test result for the model

Method	Test stat. (P-value)
$\tilde{A}$ test	2.957* (0.003)
$\tilde{A}_{adj}$ test	3.575* (0.000)
* is significant at the 1% significance level.	

Note: compiled by the authors

Given the complexity of economic relationships, the likelihood of variables affecting the econometric results of stationarity increases. Therefore, it is necessary to determine the stationarity of the variables that will be used in the analysis. Subsequently, as all variables exhibit cross-sectional dependence across countries and are heterogeneous, we employ second-generation panel stationarity tests, including CIPS, CAD, and IPS, to assess the

stationarity of the obtained panel data. The findings indicate that the examined variables, except FDI (I(0)), were non-stationary at their initial levels but attained stationarity following the application of the first difference, signifying they are integrated of order one (I(1)). The results in Table 5 indicate that all variables are I(1), signifying they are integrated of order one.

Table 5. Second-generation unit root test results

Variables/ Tests	CIPS		CAD		IPS	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
RGDP	-1.249	-3.297*	1.414	-2.151**	0.7121	-3.276*
REMIT	-1.063	-3.755*	1.504	-1.955**	-0.0048	-6.868*
TRADE	-0.692	-3.267*	1.105	-1.769**	0.6683	-4.775
FDI	-3.189*	-4.996*	-1.604***	-3.750*	-3.1274*	-8.710*
TAX	-1.895	-4.256*	0.620	-2.014**	-1.1289	-8.377*

*, ** and *** are significant at 1%, 5% and 10% significance levels.

Note: compiled by the authors

To determine the appropriate panel causality test, cross-sectional dependence in the model is also examined. The p-values of the LM, adjusted LM, and LM CD tests are below the 1% significance

level. Therefore, the null hypothesis of cross-sectional independence is rejected, indicating the presence of cross-sectional dependence in the model, as shown in Table 6.

Table 6. Cross-sectional dependence test results for the model

Test	Stat. value	p-value
LM	72.520*	0.000
LM adj	10.501*	0.000
LM CD	5.901*	0.000

The values in parentheses in the table represent probability values.

*Indicates statistical significance at the 1% level.

Note: compiled by the authors

The existence of a long-run relationship between variables can be examined using conventional cointegration tests when the variables are integrated of the same order, typically I(1). However, when some variables are I(0) and others are I(1), many conventional panel cointegration tests may not be appropriate. In such cases, alternative approaches are required. The Durbin–Hausman panel cointegration test proposed by Westerlund (2008) provides a framework for examining

cointegration when the variables have different orders of integration. The unit root test results in Table 5 indicate that foreign direct investment is stationary at I(0), whereas the remaining variables are integrated at I(1). Therefore, the Westerlund (2008) Durbin–Hausman panel cointegration test was employed to examine the long-run relationship among the variables in equation (1). The results are presented in Table 7.

Table 7. Durbin–Hausman panel cointegration test results

Cointegration Test Statistics	t-stat.	p-value
DH _s	-1.924	0.973
DH _p	1.289***	0.099

*** Indicates statistical significance at the %10 level.

Note: compiled by the authors

The DH_g statistic does not reject the null hypothesis of no cointegration, whereas the DH_p statistic provides weak evidence of cointegration at the 10% significance level. Table 7 indicates that there is no cointegrated relationship between the variables, as shown by the DH_g test results. According to the results of the DH_p test, a cointegration connection exists between the variables at the 10% significance level. The difference corresponds with the cross-section dependence heterogeneity shown for the model. The cointegration relationship is not generally applicable across all cross-sections, it exists only in certain instances, which may result in a statistically meaningful, though weak,

panel statistic. Therefore, the results should not be interpreted as contradictory but as an indication of the heterogeneous structure of the panel dataset. Consequently, it can be inferred that there is statistically supported evidence of a long-term relationship among remittances, economic growth, trade openness, foreign direct investment, and tax revenues.

After determining the existence of a long-term cointegration relationship between the variables, the long-term coefficients of the variables in the model are estimated. Table 8 shows the results of the FMOLS and DOLS estimators, indicating the long-term relationship between the variables.

Table 8. FMOLS and DOLS results

Variable	Panel FMOLS		Panel DOLS	
	Coefficient	p-value	Coefficient	p-value
TRADE	1.1260*	0.000	1.2183*	0.000
FDI	-1.7361***	0.051	-2.2875***	0.088
REMIT	10.7917**	0.0137	3.8556**	0.023
TAX	-0.0073**	0.01872	-0.0027	0.399

*, **, and *** indicate statistical significance at the 1%, 5%, and 10% levels

Note: compiled by the authors

According to Table 8, remittances have a positive and statistically significant coefficient at the 5% level in both the FMOLS and DOLS models. The estimated coefficients range from 3.8556 to 10.7917, indicating a positive long-run association between remittances and real GDP, although the magnitude differs across the two estimation methods. This difference suggests some sensitivity of the estimated effect to the econometric specification. The findings are consistent with previous studies suggesting that remittances may support economic performance through household consumption, savings, and investment channels (Eggoh et al., 2019; Kumar et al., 2018).

Upon evaluating the results of FMOLS and DOLS collectively, it is evident that the trade openness variable exerts a positive and statistically significant influence on real GDP. Thus, a 1-unit increase in trade openness is associated with an increase in real GDP ranging between 1.1260 and 1.2183. The positive and statistically significant coefficients at the 1% level in both estimation methods demonstrate that the rise in trade volume fosters long-term growth in Azerbaijan, Kazakhstan, Kyrgyzstan, Türkiye, Uzbekistan and Tajikistan.

Also, trade openness seems to be associated with positive effects on economic performance through greater integration into global markets, where export-oriented structures and access to imported intermediate inputs might result in higher productivity (Melitz, 2003; Dollar & Kraay, 2004; Amiti & Konings, 2007). In addition to this, while the FMOLS estimates suggest a statistically significant relationship between tax revenues and real GDP, the DOLS estimates show that the coefficient becomes statistically insignificant. This indicates that tax revenues may be sensitive to the estimation method employed.

On the contrary, the negative effect of foreign direct investment implies that capital inflows do not necessarily lead to stronger real GDP in the selected countries. In the selected countries, the concentration of foreign investments in sectors primarily involving natural resources, energy, or limited technology diffusion may not have contributed to growth as expected due to profit transfers and weak technological spillover effects (Alfaro et al., 2004; Asiedu, 2002; Poelhekke & van der Ploeg, 2013). Additionally, this outcome is consistent with the Dutch disease approach, which

suggests that foreign capital inflows can exert pressure on the real exchange rate, reducing the competitiveness of productive and tradeable sectors (Lartey et al., 2012; Combes et al., 2012).

The Dumitrescu-Hurlin panel causality test, formulated by Dumitrescu and Hurlin (2012), is employed in heterogeneous panel data models, as indicated by the results in Tables 3, 4, 5, and 6. Table 9 presents the outcomes of this examination.

The null hypothesis of the Dumitrescu-Hurlin causality test for panel data assumes that there is no causal relationship among the variables in the panel dataset. The alternative hypothesis states that a causal relationship exists among the variables of at least one unit. Upon analyzing Table 9, it was determined that certain variables exhibit unidirectional causation, while others demonstrate bidirectional causality and no causality.

Table 9. Dumitrescu-Hurlin panel causality test results

H ₁ hypothesis	W-stat	Z-bar statistics	P-value	Causality direction
RGDP→REMIT	1.44358	0.38552	0.6999	REMIT→RGDP
REMIT→RGDP	2.47046	1.75188***	0.0798	
RGDP→TAX	0.87343	-0.37313	0.7091	No causality
TAX→RGDP	1.31331	0.21218	0.8320	
RGDP→FDI	0.98398	-0.22602	0.8212	No causality
FDI→RGDP	0.92324	-0.30684	0.7590	
REMIT→TAX	2.63382	1.96925**	0.0489	REMIT↔TAX
TAX→REMIT	4.06146	3.86885*	0.0001	
FDI→REMIT	2.61509	1.94431***	0.0519	REMIT↔FDI
REMIT→FDI	2.75102	2.12518**	0.0336	
FDI→TAX	1.57193	0.55630	0.5780	No causality
TAX→FDI	2.27267	1.48870	0.1366	
TRADE→REMIT	2.16443	1.34467	0.1787	No causality
REMIT→TRADE	0.90201	-0.33509	0.7376	
RGDP→TRADE	0.88732	-0.35464	0.7229	TRADE→RGDP
TRADE→RGDP	2.69259	2.04745**	0.0406	
TRADE→TAX	1.69638	0.72189	0.4704	No causality
TAX→TRADE	0.39660	-1.00759	0.3137	
FDI→TRADE	2.63859	1.97559**	0.0482	FDI→TRADE
TRADE→FDI	1.59095	0.58161	0.5608	

*, **, and *** indicate statistical significance at the 1%, 5%, and 10% levels

Note: compiled by the authors

The results in Table 9 indicate a unidirectional Granger causal relationship from remittances to real GDP, from trade openness to real GDP, and from foreign direct investment to trade openness. In contrast, bidirectional Granger causal relationships are found between remittances and tax revenues and between remittances and foreign direct investment. Consistent with these findings, several studies report a predictive relationship between migrant remittances and the economic performance of recipient countries (Eggoh et al., 2019; Sobiech, 2019; Islam, 2022; Benhamou & Cassin, 2021; Kumar et al., 2018). However, other studies find no significant effect of remittances on economic growth (Dujava & Kalovec, 2020; Yadeta & Hunegnaw,

2022), while some report negative effects (Karadag et al., 2019; Bird & Choi, 2020). The bidirectional Granger causal relationship between remittances and foreign direct investment suggests a feedback mechanism in which each variable contains predictive information about the other.

The Dumitrescu-Hurlin causality test revealed no Granger causal relationship between variables. Table 9 indicates the variables for which no Granger Causal Relationship was identified. Accordingly, no predictive relationships were found between real GDP and tax revenues, between FDI and real GDP, between foreign direct investment and tax revenues, between trade openness and real GDP, and between trade openness and remittances.

CONCLUSION

This study analysed the correlation among remittances, trade openness, FDI, tax revenues, and real GDP utilising data from 2005 to 2023, encompassing five Turkic Republics (Azerbaijan, Kazakhstan, Kyrgyzstan, Türkiye, and Uzbekistan) and Tajikistan. Due to the identification of cross-sectional dependence and heterogeneity among the variables, second-generation econometric tests were employed in the analyses. The Durbin-Hausman test results by Westerlund (2008) have validated the existence of a long-term cointegration relationship among the variables.

The long-term coefficients derived from the FMOLS and DOLS estimators indicate that remittances and trade openness exert a statistically significant and positive influence on real GDP. Conversely, it has been established that FDI exert a substantial yet adverse effect on real GDP. Besides, the long-term coefficients derived from the FMOLS estimator are statistically significant, but the long-term coefficients derived from the DOLS estimator are statistically insignificant.

The FMOLS and DOLS estimates indicate that remittances and trade openness are positively and statistically significantly associated with real GDP in the long run. Remittances are significant at the 5% level in both models, while trade openness is significant at the 1% level. In contrast, FDI has a negative coefficient in both FMOLS and DOLS estimates, although the relationship is statistically significant only at the 10% level. The effect of tax revenues is less robust, as the coefficient is statistically significant in the FMOLS model but insignificant in the DOLS model.

The Dumitrescu–Hurlin panel causality results provide evidence of a one-way Granger causal relationship from remittances to real GDP at the 10% significance level. This finding suggests that remittances contain predictive information about future economic growth in the selected economies and is consistent with previous studies (Kumar et al., 2018; Abduvaliev & Bustillo, 2020). The positive long-run association between remittances and real GDP also highlights the potential role of migrant transfers in supporting domestic consumption, savings, and investment. Accordingly, policies aimed at reducing remittance transfer costs and expanding the use of formal

financial channels may strengthen the contribution of remittances to economic activity and financial inclusion, in line with SDG 10. Moreover, directing remittance resources toward education, healthcare, entrepreneurship, and productive investment may enhance their long-run contribution to economic development (Khan, 2025; Pal et al., 2022).

The results also show a negative long-run association between FDI and real GDP in the selected economies. This finding suggests that the contribution of foreign investment depends not only on its volume but also on its sectoral composition and quality. In resource-rich economies such as Azerbaijan and Kazakhstan, a substantial share of foreign investment has been concentrated in extractive industries rather than manufacturing, innovation, and research and development. Such a structure may generate relatively limited employment and technological spillovers, while weak linkages with domestic firms and the repatriation of profits may reduce the long-run growth benefits of FDI. These factors may help explain the negative FDI coefficients obtained from both the FMOLS and DOLS estimations. Therefore, policies should place greater emphasis on attracting FDI that promotes knowledge transfer, innovation, productivity growth, and stronger linkages with domestic enterprises.

The Dumitrescu–Hurlin results further indicate bidirectional Granger causality between remittances and tax revenues and between remittances and FDI. These findings suggest important interactions between migrant transfers, foreign investment, and fiscal processes. From a policy perspective, strengthening institutional quality, tax administration, financial transparency, and the formalisation of remittance-related economic activity may help broaden the tax base and improve the productive use of external financial inflows (Bangaké et al., 2025). Overall, the findings underline the importance of policies that not only attract external financial resources but also improve the institutional and financial conditions required to transform them into sustainable long-run economic growth.

AUTHOR CONTRIBUTIONS

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Economic Factors in the Development of Kazakhstan's Dairy Sector: An Econometric Analysis

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ABSTRACT

The dairy sector plays an important role in ensuring Kazakhstan's food security, but its development is characterized by structural imbalances, limited technological modernization, and high dependence on production and investment factors. The aim of the study is to evaluate the relationship of investment, price and production factors with the dynamics of milk production in Kazakhstan in 2004-2024, taking into account lag effects and the structural gap in official statistics starting in 2022. The information base was compiled by the annual data of the Food and Agriculture Organization of the United Nations and the Bureau of National Statistics of the Republic of Kazakhstan for 2004-2024. Descriptive statistics, Pearson correlation analysis, ADF and KPSS tests, multiple least squares regression, multicollinearity diagnostics, and alternative specification analysis are applied. The results showed that the preferred model explains 95.3% of the variation in milk production. The most significant positive relationship was found for real investments in agriculture ($\beta = 0.461$; $p = 0.002$) and average dairy productivity of cows ($\beta = 0.305$; $p = 0.018$). The producer price index did not demonstrate a statistically significant relationship with the volume of production ($\beta = 0.021$; $p = 0.836$). Taking into account the revision of official statistics for 2022-2024 has significantly increased the explanatory power of the model. The results show that the main factors in the development of Kazakhstan's dairy sector are investment and increased productivity, while price signals without technological modernization do not ensure a steady increase in production.

KEYWORDS: Agricultural Economy, Agro-Industrial Complex, Agriculture, Dairy Sector, Modernization, Production Efficiency, Fixed Capital, Investment Activity

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Экономические факторы развития молочного сектора Казахстана: эконометрический анализ

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АННОТАЦИЯ

Молочный сектор играет важную роль в обеспечении продовольственной безопасности Казахстана, однако его развитие характеризуется структурными диспропорциями, ограниченной технологической модернизацией и высокой зависимостью от производственных и инвестиционных факторов. Цель исследования оценить взаимосвязь инвестиционных, ценовых и производственных факторов с динамикой производства молока в Казахстане за 2004–2024 гг. с учетом лаговых эффектов и структурного разрыва официальной статистики начиная с 2022 г. Информационную базу составили ежегодные данные Продовольственной и сельскохозяйственной организации ООН и Бюро национальной статистики Республики Казахстан за 2004–2024 гг. Применены описательная статистика, корреляционный анализ Пирсона, тесты ADF и KPSS, множественная регрессия методом наименьших квадратов, диагностика мультиколлинеарности и анализ альтернативных спецификаций. Результаты показали, что предпочтительная модель объясняет 95,3% вариации объема производства молока. Наиболее значимая положительная связь установлена для реальных инвестиций в сельское хозяйство ($\beta = 0,461$; $p = 0,002$) и средней молочной продуктивности коров ($\beta = 0,305$; $p = 0,018$). Индекс цен производителей не продемонстрировал статистически значимой связи с объемом производства ($\beta = 0,021$; $p = 0,836$). Учет пересмотра официальной статистики за 2022–2024 гг. существенно повысил объясняющую способность модели. Полученные результаты показывают, что основными факторами развития молочного сектора Казахстана выступают инвестиции и повышение продуктивности, тогда как ценовые сигналы без технологической модернизации не обеспечивают устойчивого увеличения производства.

КЛЮЧЕВЫЕ СЛОВА: аграрная экономика, агропромышленный комплекс, сельское хозяйство, молочный сектор, модернизация, эффективность производства, основной капитал, инвестиционная активность

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INTRODUCTION

Milk production plays a strategic role in ensuring food security, supporting rural development, and maintaining the sustainability of the agri-food system. In Kazakhstan, dairy farming is an important branch of agriculture, supplying socially significant food products and providing raw materials for the dairy processing industry. According to the Bureau of National Statistics of the Republic of Kazakhstan, the production of all types of milk amounted to 3.63 million tonnes in 2024. However, data from 2022 onward are not directly comparable to earlier observations due to a special revision of official livestock statistics based on updated administrative records (Bureau of National Statistics, 2025). At the same time, the sector has undergone significant structural changes: the share of agricultural enterprises and farms in total milk production increased from 8.9% in 2004 to 38.9% in 2024. Nevertheless, most of the milk production still comes from household farms, which limits the adoption of modern technologies, reduces the marketability of the output, and increases regional disparities in the sector's development (FAO, 2022; OECD, 2023; FAS, 2025).

Previous studies identify investment, herd productivity, and producer prices as important factors associated with the development of dairy production. The productivity of dairy cattle farming, reflected in the average milk yield per cow, is regarded as one of the main drivers of output growth, since improvements in animal productivity make it possible to achieve a sustained increase in production volumes without a proportional expansion of the cattle population. Producer prices send market signals and influence investment decisions and output supply (Han et al., 2022; Náglová & Rudinskaya, 2021). The adoption of digital transformation tools, including supply chain digitization and predictive maintenance, can support the modernization of food production, reduce waste, and improve energy and resource efficiency (John et al., 2025).

Despite the considerable number of studies devoted to dairy-sector development, most examine individual aspects of the industry, such as farm productivity, investment activity, supply-chain organization, government support, and technological modernization (Malik et al., 2022; Headey et al.,

2024). In Kazakhstan, published studies primarily focus on assessing the current state of the industry, the challenges of innovative development, and the financial sustainability of agricultural enterprises (Baiguzhinova et al., 2025; Kireyeva et al., 2024; Akhmetova et al., 2026a; Akhmetova et al., 2026b). At the same time, there is a notable lack of research that analyzes long-term official statistical data using a unified econometric model that accounts for the lagged effects of investment and price factors, as well as the structural break in the statistical series caused by the revision of the official statistical methodology after 2021.

The aim of this study is to assess the relationship between investment, price, and production factors and the dynamics of milk production in Kazakhstan during 2004–2024, accounting for lagged effects and the structural break in official statistics beginning in 2022. The empirical analysis uses annual official statistics, descriptive analysis, Pearson correlation analysis, alternative multiple-regression specifications, multicollinearity diagnostics, and residual diagnostic tests. The estimated coefficients are interpreted as statistical associations rather than definitive causal effects.

The scientific novelty of the study lies in the joint empirical assessment of real agricultural investment, producer prices, and dairy herd productivity within a unified econometric framework that explicitly accounts for the lagged effects of economic factors and the discontinuity caused by the revision of official livestock statistics in 2022–2024. This approach provides a more cautious interpretation of long-term changes in officially recorded milk production. The findings may inform the development of agricultural policy measures to promote investment, increase dairy herd productivity, support technological modernization, and improve the sustainability of Kazakhstan's dairy sector.

LITERATURE REVIEW

Recent studies consider dairy farming to be one of the key sectors of the agri-food system, contributing to food security, rural employment, and the sustainable development of rural areas. At the same time, the efficiency of the dairy sector is determined not only by production volumes but also by a combination of economic, production, and institutional factors that influence productivity, investment activity, and the

competitiveness of producers (Arvidsson Segerkvist et al., 2020; Fiorillo & Amico, 2024; Adesogan & Dahl, 2020). Studies focusing on Kazakhstan also emphasize the persistent structural problems of the sector, including the high share of household farms, regional disparities in production, an insufficient level of technological modernization, and the need to improve the investment attractiveness of dairy farming (Smagulova et al., 2023; Akhmedyarov et al., 2023; Yesbolova et al., 2025; Jussibaliyeva et al., 2022; Sun et al., 2026). Recent Kazakhstan-specific research also identifies the main prospects for the sustainable development of the dairy sector and emphasizes the importance of technological modernization, investment activity, and institutional support (Baiguzhinova et al., 2025).

Despite the considerable number of publications, research on the factors influencing the development of the dairy sector remains relatively fragmented. A substantial proportion of studies focus on individual elements of the production and distribution chain, including production organization, processing, logistics, supply integration, and risk management (Guarnaschelli et al., 2020; Hassan et al., 2021; Azisafaei et al., 2022; Vieira et al., 2020; Danese et al., 2020). This approach allows individual processes to be examined in detail; however, it limits understanding of how macroeconomic and production factors jointly determine national-level milk production dynamics. Optimization methods are increasingly applied to improve production planning, logistics, and resource allocation across dairy supply chains (Malik et al., 2022).

Investment is recognized in academic literature as one of the most robust determinants of milk production growth. Economic theory suggests a positive relationship between capital investment and production volume, driven by the modernization of production facilities, the introduction of new technologies, and more efficient resource utilization. Empirical studies confirm that investment contributes to increased productivity in dairy cattle farming, although its impact most often occurs with a certain time lag, since the effects of farm construction, equipment acquisition, and herd renewal materialize gradually (Ma et al., 2020; Olagunju et al., 2022; Śwityk et al., 2021). More broadly, R&D expenditure and technological innovation are significantly associated with economic growth in Kazakhstan, although the

direction and strength of these relationships vary across individual indicators (Kireyeva et al., 2021). At the sectoral level, the sustainability of dairy enterprises' investments is regarded as an important prerequisite for improving the competitiveness of Kazakhstan's dairy sector (Akhmetova et al., 2024). Accordingly, this study assumes that real investment in agricultural fixed capital has a positive effect on milk production volume.

Recent studies also emphasize the role of digital transformation in improving production efficiency. Supply chain digitization and predictive maintenance can reduce waste and improve energy and resource efficiency in food production and distribution (John et al., 2025). A systematic review by Akhmetova et al. (2026a) demonstrates the importance of agribusiness digitalization for productivity and sustainability, while Akhmetova et al. (2026b) provide dairy-specific evidence on the relationship between digital transformation and the economic efficiency of dairy farms in Kazakhstan.

Another important production factor is dairy herd productivity. Unlike the extensive expansion of the cattle population, an increase in average milk yield reflects improvements in production efficiency, breeding practices, the feed base, and animal housing conditions. A study by Bórawski et al. (2020), conducted across European Union countries, showed that differences in milk production volumes are largely explained by variations in animal productivity and resource availability. Similar conclusions were presented by Bianchi et al. (2022), Kosar et al. (2022), and Klapkiv et al. (2023), who identify productivity growth as the main source of long-term production expansion. Náglová and Rudinskaya (2021) examine the factors influencing the technical efficiency of dairy farms in the European Union, while Han et al. (2022) analyze productive efficiency and trade opportunities for dairy farms in Kazakhstan.

Considerable attention in the economic literature is devoted to price-related factors. According to classical economic theory, an increase in producer prices should stimulate an expansion of product supply by raising the expected profitability of production. However, research shows that this mechanism does not always operate directly. In dairy farming, producers' responses to price changes are usually delayed, since adjustments in production volumes require time to expand the herd, implement

investment projects, and adapt production processes (Ben Abdallah et al., 2020; Hillen, 2021). In addition, research findings indicate asymmetric price transmission along the value chain, whereby increases in producer selling prices only partially offset rising production costs (Onegina et al., 2022; Rudinskaya & Boskova, 2021). Costa et al. (2022) also note that differences in farm-gate milk prices have varying effects on the efficiency of different types of farms. Accordingly, this study assumes a positive, albeit potentially less pronounced, relationship between the producer price index and milk production volume.

Domestic demand is another important factor in the sector's development. Growth in the consumption of milk and dairy products creates incentives to expand production; however, the impact of demand is primarily reflected in long-term structural changes in the market. Studies by Cheng et al. (2022), Headey et al. (2024), Liang et al. (2020), Jia et al. (2022), and Kimsanova et al. (2024) show that dairy consumption is determined by household income levels, demographic changes, urbanization, and dietary preferences. At the same time, consumption is closely associated with several other macroeconomic indicators, increasing the risk of multicollinearity among the explanatory variables when constructing regression models. For this reason, the consumption indicator was included in the preliminary stage of the analysis, and its effect was assessed alongside multicollinearity diagnostics and comparisons of alternative model specifications.

The official revision of statistical data by the Bureau of National Statistics of the Republic of Kazakhstan is particularly important for interpreting the results (Bureau of National Statistics, 2025). Beginning in 2022, selected livestock statistics for peasant (farm) enterprises and household farms were revised on the basis of updated administrative data from farm household records, in accordance with

the Rules for Revising Published Official Statistical Information for Statistical Purposes. This revision resulted in a structural break in the milk production series, reflecting a change in statistical methodology rather than economic processes alone.

Thus, the literature review shows that most studies examine the effects of individual factors influencing the development of the dairy sector—investment, productivity, prices, or consumption—primarily in isolation. In Kazakhstan, there remains a lack of research that integrates macroeconomic and production indicators into a unified econometric model that accounts for the lagged effects of economic factors and the structural break in the official statistical series. Addressing this research gap determines the present study's focus and the selection of explanatory variables.

METHODOLOGY

The empirical dataset comprised official FAO and Bureau of National Statistics data for 2004–2024 on the development of dairy farming in Kazakhstan. The volume of milk production across all types, measured in thousand tonnes, was used as the dependent variable. At the initial stage, an expanded set of macroeconomic and production indicators was compiled, including the producer price index for raw milk, fixed-capital investment in agriculture, per capita consumption of milk and dairy products, the share of agricultural enterprises and farms in total milk production, average milk yield, the number of cows, gross output from dairy cattle farming, foreign trade indicators, the share of agriculture in GDP, pasture area, the GDP deflator, and population size. The final set of factors was determined based on the results of correlation analysis, multicollinearity diagnostics, and the economic interpretation of the models (Table 1).

Table 1. Variables included in the preferred regression model

Variable	Unit of measurement	Transformation
Milk production across all farm categories	Thousand tonnes	Dependent variable
Real fixed-capital investment in agriculture	Million KZT at constant 2024 prices	One-year lag
Producer price index for raw milk	Percent	One-year lag
Average milk yield per cow	Kilograms per cow	Current value
Statistical revision dummy	Binary variable	1 for 2022–2024; 0 otherwise

Note: compiled by the authors based on FAO (2025) and Bureau of National Statistics (2025)

Investment values were expressed in constant 2024 prices using the GDP deflator, thereby removing the effect of inflation. Given the delayed effect of investment, real investment was included in the model with a one-year lag. A similar lag was applied to the producer price index because producers' responses to price changes also occur with a time lag.

To ensure comparability with the data, changes to the official statistical methodology were taken into account. In accordance with the Rules for Revising Published Official Statistical Information, the Bureau of National Statistics of the Republic of Kazakhstan conducted a special revision of selected livestock indicators for 2022-2023 based on updated administrative data from household records (Bureau of National Statistics, 2025). Consequently, a dummy variable was included in the model, taking the value of 1 for the period 2022-2024 and 0 for the preceding years.

The initial dataset included 21 annual observations for 2004–2024. Because of the use of one-year lags, the preferred regression model was estimated with 20 observations. Before estimating the regression models, the stationarity of the time series was assessed using the augmented Dickey–Fuller and KPSS tests.

The study involved the sequential application of descriptive statistics, Pearson correlation analysis, and multiple regression using the ordinary least squares (hereinafter – OLS) method. To assess the robustness of the results, several alternative specifications were estimated, including linear, lagged, and log-linear models, as well as a model accounting for the structural break in the statistical series.

The empirical analysis was conducted in six stages:

- (1) data collection and preparation;
- (2) descriptive statistical analysis;
- (3) stationarity testing using the ADF and KPSS tests;

(4) correlation analysis and multicollinearity diagnostics;

(5) estimation and comparison of alternative OLS specifications;

(6) model diagnostics and robustness testing.

The alternative specifications included linear, lagged, and log-linear models, as well as models with and without the statistical revision dummy. Model quality was evaluated using the coefficient of determination (R^2), adjusted R^2 , RMSE, and the F-test. Model diagnostics included variance inflation factors (hereinafter – VIF), the Breusch-Pagan test for heteroskedasticity, HC3-robust standard errors, the Durbin–Watson and Breusch-Godfrey tests for autocorrelation, the Ramsey RESET test for model specification, and the Jarque-Bera test for the normality of residuals. In addition, standardized β coefficients were calculated to compare the relative strength of the explanatory factors' effects.

All calculations were performed using MATLAB R2024b. The critical level of statistical significance was set at $p < 0.05$, while results with $p < 0.10$ were considered marginally statistically significant.

RESULTS

An analysis of the data for 2004-2024 indicates that the development of dairy farming in Kazakhstan was characterized by uneven dynamics in both production and macroeconomic factors. Between 2004 and 2021, milk production increased from 4,556.8 to 6,247.2 thousand tonnes; however, beginning in 2022, the official time series shows a sharp decline. This break does not reflect an actual reduction in production but is attributable to the revision of the official statistical methodology and the use of updated administrative data in compiling livestock indicators. Descriptive statistics for the indicators under study are presented in Table 2.

Table 2. Descriptive statistics of the study variables for 2004–2024

Variable	N	Mean	Median	Std. Dev.	CV, %	Minimum	Maximum
Milk production, thousand tonnes	21	5,028.7	5,182.4	768.73	15.29	3,354.6	6,247.2
Producer price index, %	21	109.77	109.60	7.16	6.53	97.80	127.70
Real agricultural investment, million KZT	21	565,480	413,240	269,170	47.60	285,450	1,103,500
Per capita dairy consumption, kg/year	21	224.86	227.20	20.53	9.13	189.10	261.30
Total dairy consumption, thousand tonnes	21	4,062.3	4,019.4	664.12	16.35	3,008.4	5,053.7
Organized-sector share, %	21	20.05	18.13	10.17	50.75	8.90	38.90
Average milk yield, kg/cow	21	2,295.2	2,280.0	111.17	4.84	2,108.0	2,542.0

* Monetary indicators are expressed in constant 2024 prices.

Note: authors' calculations based on official statistics and MATLAB estimates

The indicators presented in the table show that real investment in agricultural fixed capital and the share of agricultural enterprises and farms in total milk production exhibited the greatest variability, reflecting the scale of the sector's structural modernization. By contrast, the producer price index and average milk yield changed much more

gradually. Per capita consumption of milk and dairy products also showed relatively low variability, indicating stable domestic demand throughout the period under review.

Figure 1 shows that until 2021, growth in milk production was accompanied by a steady increase in average milk yield per cow.

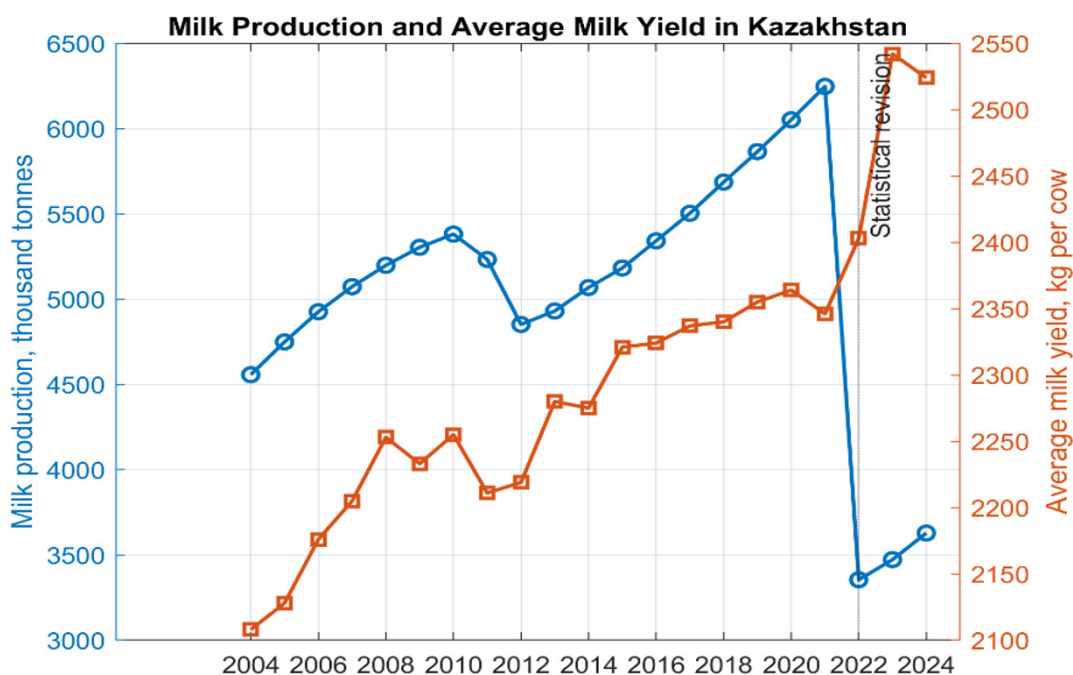


Figure 1. Dynamics of milk production and average milk yield in Kazakhstan for 2004-2024

This indicates a gradual shift in the sources of sectoral growth from the extensive expansion of the cattle population toward improvements in animal productivity. After 2022, despite the sharp decline in officially reported production volume due to a change in statistical methodology, the average milk yield continued to increase, further confirming the

absence of any actual deterioration in production efficiency.

To provide a preliminary assessment of the relationships among the variables, a correlation analysis was conducted, and the results are presented in Table 3.

Table 3. Pearson correlation matrix

Variable	Milk production	Producer price index	Real investment	Total consumption	Milk yield	Organized share	Dummy 2022
Milk production	1.000	-	-	-	-	-	-
Producer price index	-0.140	1.000	-	-	-	-	-
Real investment	-0.083	0.120	1.000	-	-	-	-
Total consumption	0.111	-0.091	0.824***	1.000	-	-	-
Milk yield	-0.315	-0.009	0.757***	0.829***	1.000	-	-
Organized share	-0.298	-0.027	0.894***	0.890***	0.936***	1.000	-
Dummy 2022	-0.840***	0.187	0.539*	0.367	0.732***	0.719***	1.000

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. Pearson correlation coefficients are reported

Note: compiled by the authors

The correlation matrix reveals that the full-sample pairwise relationships between milk production and real investment ($r = -0.083$), average milk yield ($r = -0.315$), and the organized-sector share ($r = -0.298$) are weak and negative. These coefficients should not be interpreted as evidence of adverse economic effects, since they are strongly influenced by the structural break in the official production series after 2022. This interpretation is supported by the strong negative correlation between milk production and the statistical revision dummy ($r = -0.840$; $p < 0.001$). By contrast, real investment is strongly correlated with total consumption ($r = 0.824$), average milk yield ($r = 0.757$), and the organized-

sector share ($r = 0.894$), while the organized-sector share is closely associated with average milk yield ($r = 0.936$). These relationships indicate that capitalization, productivity growth, market expansion, and organizational transformation occurred simultaneously, thereby creating a potential multicollinearity risk that was addressed through alternative model specifications and VIF diagnostics. The producer price index exhibits only weak correlations with the other variables.

Before estimating the regression models, the stationarity of the time series was tested using the augmented Dickey-Fuller test. The results are presented in Table 4.

Table 4. Augmented Dickey–Fuller unit root test

Variable	ADF p-value, level	ADF p-value, first difference	KPSS p-value, level	Inference
Milk production	0.686	0.001	0.012	I(1)
Real investment	0.615	0.006	0.010	I(1)
Producer price index	0.021	0.001	0.100	I(0)
Total consumption	0.662	0.001	0.013	I(1)
Milk yield	0.503	0.001	0.058	Trend-stationary/ borderline
Organized share	0.598	0.036	0.010	I(1)

For the ADF test, the null hypothesis is the presence of a unit root; for the KPSS test, the null hypothesis is stationarity. Note: compiled by the authors

The tests indicated mixed stationarity properties across the variables. Milk production, real investment, total consumption, and the organized-sector share were classified as I(1), while the producer price index was stationary in levels and average milk yield was trend-stationary or borderline. These properties should be considered when interpreting the regression results. In addition, the structural break in the official time series after 2022 was accounted for by including a dummy variable,

thereby preserving the economic interpretability of the model and reducing the risk of biased coefficient estimates.

Following the preliminary data analysis, several alternative multiple regression specifications were estimated. These differed in the composition of the explanatory variables, the use of lagged effects, and the method employed to account for the structural break in the official time series. A comparison of the models is presented in Table 5.

Table 5. Comparison of alternative regression models

Model	Main explanatory variables	N	R ²	Adjusted R ²	RMSE	AIC	BIC
M1	Milk yield + lagged real investment + lagged PPI + Dummy 2022	20	0.953	0.940	191.1	271.1	276.1
M2	Real investment + total consumption + PPI + Dummy 2022	21	0.930	0.913	227.3	291.8	297.0
M3	Organized share + total consumption + PPI + Dummy 2022	21	0.920	0.900	243.0	294.6	299.8
M4	Pre-2022 lagged specification	17	0.820	0.778	199.8	231.8	235.1
M5	Milk yield + current real investment + PPI + Dummy 2022	21	0.948	0.934	196.8	285.7	291.0
M6	Real investment + total consumption + milk yield + PPI + Dummy 2022	21	0.948	0.930	203.2	287.7	294.0

Note: compiled by the authors

The comparison shows that all models demonstrate a high goodness of fit; however, model M1 exhibits the best statistical characteristics. This model includes lagged real investment, the lagged producer price index, average milk yield, and a dummy variable accounting for the change in the official statistical methodology after 2022. For this model, the coefficient of determination is $R^2 = 0.953$, the adjusted coefficient of determination is 0.940, and the F-statistic is statistically significant at $p < 0.001$, indicating the model's high explanatory power.

The use of a lag structure proved to be both economically and statistically justified. Unlike current investment, capital investment affects milk production only after the completion of the investment cycle, through the modernization of production facilities and the introduction of new technologies. Similarly, producers' responses to changes in purchase prices are delayed due to the biological characteristics of dairy farming.

The estimation results for the preferred model are presented in Table 6.

Table 6. Regression results for the preferred lagged model

Variable	Coefficient	OLS SE	OLS t-statistic	OLS p-value	HC3 robust SE	HC3 p-value	Standardized β
Intercept	−684.110	2,062.400	−0.332	0.745	2,272.600	0.768	–
Average milk yield	2.264	0.835	2.713	0.016	0.850	0.018	0.305
Lagged real agricultural investment	0.001318	0.000314	4.198	0.001	0.000342	0.002	0.461
Lagged producer price index	2.251	6.626	0.340	0.739	10.714	0.836	0.021
Statistical revision dummy, 2022–2024	−3,091.200	208.020	−14.860	<0.001	194.980	<0.001	−1.450
Model fit statistics							
Observations	20						
R ²	0.953						
Adjusted R ²	0.940						
RMSE	191.1						
F-statistic	75.6						
Model p-value	<0.001						
The dependent variable is milk production, measured in thousand tonnes. Real agricultural investment is expressed in constant 2024 prices and included with a one-year lag. The producer price index is also included with a one-year lag. The statistical revision dummy equals 1 for 2022–2024 and 0 otherwise. OLS SE denotes the conventional OLS standard error, while HC3 robust SE denotes the heteroskedasticity-consistent standard error. Standardized β coefficients are reported only for continuous explanatory variables.							

Note: compiled by the authors

The estimates show that real investment in agricultural fixed capital has the greatest impact on milk production volume. The coefficient on lagged investment remains positive and statistically significant both with conventional standard errors and after the HC3 correction. According to the estimate, a KZT 1 billion increase in real investment is associated with an increase in milk production of approximately 1.318 thousand tonnes in the following year, *ceteris paribus*. The standardized coefficient ($\beta = 0.461$) is the highest among the continuous factors included in the model, indicating that investment activity plays the leading role in the long-term development of the dairy sector.

Average milk yield per cow is another important factor. An increase of 100 kg in productivity

is associated with an increase in production of approximately 226.4 thousand tonnes, while the standardized coefficient ($\beta = 0.305$) confirms the substantial contribution of technological improvement and production efficiency. The joint significance of investment and productivity indicates that sustainable production growth is achieved primarily through sectoral modernization and more efficient use of resources.

In contrast to the aforementioned factors, the lagged producer price index did not demonstrate a statistically significant independent effect. This indicates that short-term changes in purchase prices alone are insufficient to sustain increases in production volumes without corresponding capital investment and productivity growth.

As shown in Figure 2, the fitted values closely track the long-term dynamics of milk production, including the shift in the level of the time series after 2022.

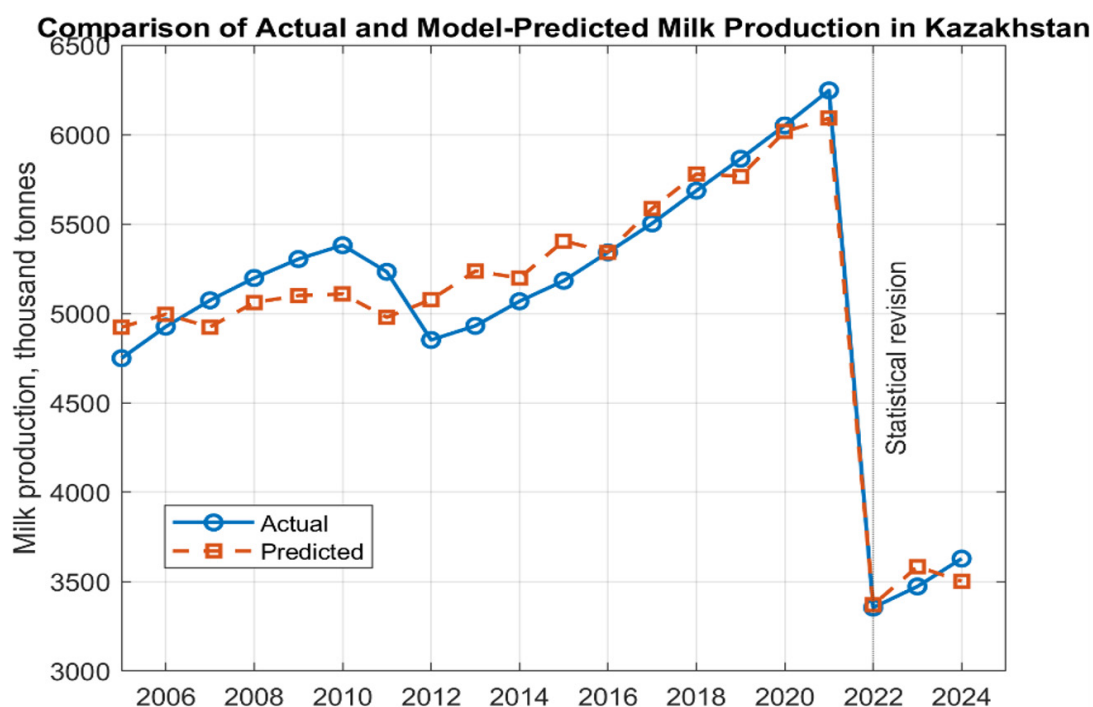


Figure 2. Actual versus predicted milk production

The coefficient on the 2022–2024 dummy variable, which reflects the effect of the change in statistical methodology, is of particular importance. Its negative and highly statistically significant value indicates a structural break in the official time series, attributable to the revision of administrative data rather than to an actual decline in milk production. Consequently, ignoring this effect would have

resulted in substantial bias in the model parameters.

The absence of systematic deviations between the actual and predicted values confirms the adequacy of the selected specification and the correct treatment of the structural break in the official statistics. The reliability of the estimates obtained was additionally assessed using a set of diagnostic procedures, the results of which are presented in Table 7.

Table 7. Regression diagnostic tests

Diagnostic	Statistic	Result	Interpretation
Maximum VIF	4.013	< 5	No severe multicollinearity
Breusch–Pagan LM	5.458	$p = 0.243$	Homoskedasticity is not rejected
Jarque–Bera	0.996	$p = 0.408$	Residual normality is not rejected
Durbin–Watson	1.005	Below 2	Possible positive residual autocorrelation
Ramsey RESET	5.204	$p = 0.022$	Possible functional-form incompleteness
Maximum Cook's distance	0.439	< 1	No single observation is overwhelmingly influential
Observations above Cook's 4/n threshold	1	–	Sensitivity check recommended
HC3 robust inference	Applied	–	Coefficient inference robust to heteroskedasticity

Note: compiled by the authors

The inclusion of a dummy variable reflecting the change in official statistical methodology in 2022–2024 allowed the structural break in the

time series to be accounted for and reduced the risk of biased parameter estimates. The diagnostic procedures indicated no severe multicollinearity

or heteroskedasticity and did not reject residual normality. However, the Durbin–Watson statistic suggested possible positive autocorrelation, while the Ramsey RESET test indicated possible functional-form misspecification. Therefore, the estimated coefficients should be interpreted as robust statistical associations rather than definitive causal effects.

The robustness of the results was further assessed through a sequential comparison of alternative specifications. In model M2, the positive effect of dairy product consumption persists; however, after applying HC3 robust standard errors, its statistical significance becomes marginal. In model M3, the inclusion of the share of agricultural enterprises leads to a substantial

increase in multicollinearity, indicating a strong interrelationship among the processes of capitalization, productivity growth, and institutional transformation within the sector. Models M4 and M5 confirm the robustness of the positive effect of investment regardless of whether the period of statistical revision is considered, whereas the inclusion of additional factors in M6 provides virtually no improvement in model quality and only strengthens the interrelationships among the regressors. Overall, the comparison results confirm that model M1 provides the most robust and economically interpretable estimates.

The estimation results of the log-linear model are presented in Table 8.

Table 8. Log-linear robustness model

Variable	Coefficient	Standard error	t-statistic	p-value
Intercept	−4.1965	2.6817	−1.565	0.137
Producer price index	0.001868	0.001329	1.405	0.179
Log of real agricultural investment	0.065632	0.031913	2.057	0.056
Log of average milk yield	1.5155	0.3762	4.028	0.001
Statistical revision dummy, 2022–2024	−0.60945	0.03791	−16.075	<0.001
Model fit statistics				
Model statistic	Value			
Observations	21			
R ²	0.953			
Adjusted R ²	0.942			
RMSE	0.0405			
F-statistic	81.6			
Model p-value	<0.001			
The dependent variable is the natural logarithm of milk production. Real agricultural investment and average milk yield are also expressed in natural logarithms. Accordingly, their coefficients can be interpreted as elasticity. The producer price index is included in levels. The statistical revision dummy equals 1 for 2022–2024 and 0 otherwise.				

Note: compiled by the authors

The logarithmic specification confirmed the robustness of the conclusions obtained from the linear model. The coefficient on the logarithm of average milk yield was 1.5155 and was statistically significant at the 1% level ($p = 0.001$), allowing it to be interpreted as an elasticity coefficient: a 1% increase in average milk yield is associated with an approximately 1.52% increase in milk production, *ceteris paribus*. The elasticity with respect to real investment was 0.0656 and was statistically significant at the 10% level ($p = 0.056$), indicating a positive, although comparatively moderate, effect of capital investment. As in the linear model, the producer price index did not demonstrate a statistically significant independent effect.

The dummy variable for the period 2022–2024

remained highly statistically significant ($p < 0.001$), confirming the robustness of the structural break in the time series. Given the logarithmic form of the model, the corresponding coefficient is equivalent to a decrease of approximately 45.6% in the conditional level of officially recorded production, reflecting the consequences of the change in statistical methodology and the updating of administrative data rather than an actual decline in milk production. Thus, the log-linear model supports the conclusions of the main specification and demonstrates the robustness of the results regardless of the functional form of the relationship.

To assess the effect of accounting for the structural break, models with and without the dummy variable were directly compared (Table 9).

Table 9. Effect of accounting for the structural break on model performance

Model performance statistic	Without structural dummy	With structural dummy (2022–2024)	Change
Observations (N)	21	21	—
Adjusted R ²	0.050	0.934	+0.884
RMSE (thousand tonnes)	749.13	196.79	–73.7%
AIC	341.15	285.73	–55.42
BIC	345.33	290.96	–54.37

Note: The model without the dummy variable ignores the statistical revision of official livestock data introduced in 2022. The second specification includes a dummy variable equal to 1 for 2022–2024 and 0 otherwise. Lower values of RMSE, AIC and BIC indicate superior model performance.

Note: compiled by the authors

Accounting for the structural break caused by the revision of the official statistical methodology in 2022 substantially improves the fit of the econometric model. The inclusion of the dummy variable increases the adjusted coefficient of determination from 0.050 to 0.934, reduces the model's root mean square error by almost 74%, and substantially lowers the AIC and BIC values. The results show that omitting the structural-break dummy substantially worsens model fit and may bias the estimated coefficients. Therefore, the use of a dummy variable is a necessary for reducing specification bias and improving comparability of the factors influencing the development of milk production in Kazakhstan.

The positive effect of investment identified in this study is consistent with recent research on the technological modernization of dairy farms, while also allowing the temporal mechanism of this effect to be specified more precisely. Using data from 251 dairy farms in China, Yu et al. (2025) found that a 1% increase in digital investment raises technical efficiency by an average of 0.029%. After accounting for potential endogeneity and conducting robustness checks, the estimated effect ranged from 0.015% to 0.085%. In the present study, the elasticity of milk production with respect to real investment was 0.0656 ($p = 0.056$), while the standardized coefficient of lagged investment in the linear model reached $\beta = 0.461$ ($p = 0.002$). Despite differences in the dependent variables, the direction of the results is consistent, and the elasticity estimated for Kazakhstan falls within the range reported by Yu et al. (2025). An important distinction is the identified one-year lag: capital investment affects output after equipment has been commissioned, farms have been modernized, and the production base has been renewed. This interpretation is consistent with the dynamic analysis by Ali (2021), according to which

the average productivity growth of Dutch dairy farms was 1.1% per year, including 0.5% attributable to technical progress, while the returns to quasi-fixed resources depended on the intertemporal costs of their adjustment.

The substantial effect of average milk yield is also consistent with the findings of international studies; however, in the present research, this effect is quantitatively assessed for the first time at the level of Kazakhstan's national milk production. Based on an analysis of more than 5,400 observations from Swiss dairy farms, Schorr and Lips (2018) found that an increase in milk yield of 1,000 kg per cow raised annual income per family worker by an average of CHF 2,660, or approximately 6%. For the most successful group of farms, the effect reached CHF 7,210, or about 16%, whereas for the least efficient farms, further increases in milk yield did not necessarily improve financial performance. In the model for Kazakhstan, a 100 kg increase in average milk yield is associated with an increase in production of approximately 226.4 thousand tonnes; the standardized coefficient is $\beta = 0.305$ ($p = 0.018$), while the logarithmic specification yields an elasticity of 1.5155 ($p = 0.001$). Therefore, improvements in herd productivity represent a significant source of growth in aggregate output, although the findings of Schorr and Lips (2018) indicate that the economic return from higher milk yields at the individual farm level may depend on management quality and the farm's initial level of efficiency.

The absence of an independent effect of the producer price index does not contradict research on price transmission, since price changes along the value chain and the response of physical output represent distinct economic processes. Using monthly data from the South African dairy industry for 2000–2024, Ramakgasha and Thaba (2026) identified asymmetric price transmission among

the farm, processing, and retail levels. The speed of adjustment toward long-run equilibrium was approximately 32%, while the transmission of price changes from the farm level to retail was about 51%. In the present study, the lagged producer price index has a very small standardized coefficient of $\beta = 0.021$ and remains statistically insignificant after the HC3 correction ($p = 0.836$); its effect is also insignificant in the logarithmic model ($p = 0.179$). This means that price changes may be transmitted among participants in the dairy value chain, but they do not, by themselves, ensure an expansion of production in the absence of investment, technological upgrading, and productivity growth.

The findings regarding domestic demand also require a differentiated interpretation. Applying the Almost Ideal Demand System model to panel data from rural households in Bangladesh, Mahfuza et al. (2024) obtained positive expenditure elasticities for liquid, powdered, and condensed milk of 1.013, 1.856, and 1.060, respectively. These estimates indicate that an increase in household purchasing power can substantially raise the consumption of dairy products. In the present study, the models that included aggregate consumption demonstrated lower quality than the preferred specification incorporating lagged investment and herd productivity (Table 4). After accounting for production factors in the final model, real investment ($\beta = 0.461$; $p = 0.002$) and average milk yield ($\beta = 0.305$; $p = 0.018$) retained the strongest effects, while the consumption indicator was not included in the final specification. This suggests that domestic demand determines the size of the dairy market, whereas long-term production growth is driven to a greater extent by investment activity and improvements in animal productivity.

The increase in the share of agricultural enterprises and farms from 8.9% to 38.9% indicates the continuing organizational transformation of Kazakhstan's dairy sector. The institutional significance of this process is supported by the findings of Kaliyeva et al. (2021): the adjusted willingness of Kazakhstan's citizens to pay for a policy supporting the establishment of dairy cooperatives amounted to KZT 86.61 per litre, or approximately 29% of the market price, while the aggregate public valuation of such a policy reached approximately KZT 267 billion per year. At the same time, the results of the correlation analysis show a strong relationship between the share of the

organized sector and real investment ($r = 0.894$), as well as average milk yield ($r = 0.936$), indicating that the processes of organizational concentration, capital accumulation, and technological modernization occur simultaneously. Therefore, the development of organized forms of farming should be regarded primarily as an institutional foundation for increasing investment activity and productivity rather than as an independent factor driving growth in production volumes.

Overall, comparison with international studies shows that the long-term growth of milk production is driven not by a single factor but by an interconnected process of capital accumulation, technological change, and productivity improvement. In Kazakhstan, the strongest continuous factor is lagged real investment ($\beta = 0.461$; $p = 0.002$), followed by average milk yield ($\beta = 0.305$; $p = 0.018$), whereas the lagged producer price index has no independent effect ($\beta = 0.021$; $p = 0.836$). An additional feature of the Kazakhstani time series is the statistical revision of data after 2022: including the corresponding dummy variable increases the adjusted R^2 from 0.050 to 0.934 and reduces the RMSE by 73.7%. Therefore, the estimated coefficients should be interpreted in light of the fact that the sharp change in officially recorded production primarily reflects the updating of administrative data and statistical methodology rather than a comparable economic decline in physical output. Official publications of the Bureau of National Statistics also indicate that special revisions of livestock indicators were conducted on the basis of updated administrative data from farm records.

CONCLUSION

The study provided a comprehensive economic assessment of the factors determining the dynamics of milk production in Kazakhstan, based on official statistical data for 2004-2024. Unlike most previously published studies, the analysis focused on the joint consideration of macroeconomic and production factors, taking into account the specific features of national statistics and the structural revision of data conducted beginning in 2022.

The results showed that real investment in the fixed capital of agriculture and average milk yield per cow have the greatest influence on milk production volume. The use of a lagged specification confirmed

that the effect of investment is not immediate but occurs with a time delay, which is consistent with the economic nature of the investment process. By contrast, the producer price index did not demonstrate a statistically significant independent effect after production factors were considered, indicating that price signals alone do not ensure sustainable production growth without improvements in the sector's technological efficiency.

The inclusion of a dummy variable reflecting the change in official statistical methodology in 2022–2024 allowed the structural break in the time series to be explicitly accounted for and reduced the risk of biased parameter estimates. The diagnostic procedures indicated no severe multicollinearity or heteroskedasticity and did not reject residual normality. However, the Durbin–Watson statistic suggested possible positive residual autocorrelation, while the Ramsey RESET test indicated possible functional-form incompleteness. Therefore, the estimated coefficients should be interpreted as statistically robust associations rather than definitive causal effects.

The findings can inform government support measures for the dairy sector aimed at stimulating long-term investment, increasing dairy cattle productivity, and promoting technological modernization. The proposed approach also makes it possible to account for the effects of changes in official statistical methodology when analyzing long-term time series.

A limitation of the study is its reliance on aggregated annual national-level data, which do not capture regional heterogeneity in dairy farming or differences among producer categories. A promising direction for further research is the development of panel data models for the regions of Kazakhstan, as well as the inclusion of additional indicators characterizing government support for the sector, foreign trade activity, climatic conditions, and the technological level of agricultural enterprises.

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Conceptualization and theory: YD and LA; research design: YD, LA, AB, AA and ID; data collection: YD, LA, AB, AA and ID; analysis and interpretation: YD, LA, AB, AA and ID; writing draft preparation: YD, LA, AB, AA and ID; supervision: AB, AA and ID; correction of article: YD, LA, AB, AA and ID; proofread and final

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Financial Literacy, Financial Well-being and Stock Market Participation: Evidence from Oman

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ABSTRACT

The population's participation in the stock market depends not only on the availability of investment instruments but also on financial knowledge and assessments of one's own financial situation. This study examines financial literacy and stock market participation in Oman, considering demographic differences and the role of financial well-being in their relationship. The study uses methods of descriptive statistics, hierarchical binary logistic regression, and the Karlson–Holm–Breen (KHB) decomposition method. The empirical basis consisted of the results of an online survey conducted from February to June 2026 in Muscat, Salalah, and Sohar. Of the 1,000 questionnaires distributed, 786 responses were received; after verification, 739 respondents were included in the final sample. The results showed relatively low objective financial literacy: 47% of respondents answered questions about interest rates correctly, 41% about inflation, and 36% about financial risks. At the same time, 62% of participants reported a high level of financial well-being, while only 26% reported participating in the stock market. Regression analysis revealed a positive relationship between financial literacy and participation in the stock market (odds ratio — 1.42 in the second model and 1.33 in the third), while for financial well-being, this indicator was 1.25. Additional analysis indicates its possible mediating role in the relationship under consideration. The obtained results indicate the need to develop practical financial skills among the population of Oman, along with increasing the availability of investment services.

KEYWORDS: Financial Economy, Financial Literacy, Financial Well-Being, Stock Market, Investment Behavior, Inflation, Oman

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Финансовая грамотность, финансовое благополучие и участие в фондовом рынке: эмпирические данные Омана

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АННОТАЦИЯ

Участие населения в фондовом рынке определяется не только доступностью инвестиционных инструментов, но и уровнем финансовых знаний, а также оценкой собственного финансового положения. Цель исследования — оценить взаимосвязь финансовой грамотности и участия населения Омана в фондовом рынке с учётом социально-демографических различий и роли финансового благополучия в данной взаимосвязи. В работе использованы методы описательной статистики, иерархическая бинарная логистическая регрессия и метод декомпозиции Карлсона–Холма–Брина (КНВ). Эмпирическую основу составили результаты онлайн-опроса, проведённого с февраля по июнь 2026 года в Маскате, Салале и Сохаре. Из 1000 распространённых анкет получено 786 ответов, после проверки в итоговую выборку включены 739 респондентов. Результаты показали сравнительно низкий уровень объективной финансовой грамотности: на вопросы о процентных ставках правильно ответили 47% респондентов, об инфляции — 41%, о финансовых рисках — 36%, при этом 62% участников отметили высокий уровень финансового благополучия, а об участии в фондовом рынке сообщили только 26%. Регрессионный анализ выявил положительную связь финансовой грамотности с участием в фондовом рынке (отношение шансов — 1.42 во второй модели и 1.33 в третьей), тогда как для финансового благополучия данный показатель составил 1.25. Дополнительный анализ указывает на его возможную посредническую роль в рассматриваемой взаимосвязи. Полученные результаты свидетельствуют о необходимости развития практических финансовых навыков населения Омана наряду с повышением доступности инвестиционных услуг.

КЛЮЧЕВЫЕ СЛОВА: финансовая экономика, финансовая грамотность, финансовое благополучие, фондовый рынок, инвестиционное поведение, инфляция, Оман

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INTRODUCTION

Stock market participation is an important driver of financial system development and personal wealth accumulation. It may also contribute to individuals' sense of financial security and well-being (Liu et al., 2024; Yun & Mao, 2025). This issue is particularly relevant to Oman, a high-income economy with a developing stock market. According to FinStatGlobe (2026), stock market activity accounted for 3% of Oman's GDP, compared with the regional average of 8.7%. Low stock market participation is not unique to Oman and is widely discussed in the literature as the stock market participation puzzle (Duraj et al., 2025).

A thorough literature review shows that stock market participation is influenced by numerous factors, including stock expectations, the nature of stocks, the risks involved, and risk preferences (Menkhoff & Westermann, 2025). Agarwal et al. (2026) found that government-provided infrastructure and facilities influence individuals' investment behavior, as they tend to receive more information, access to resources, and development opportunities that encourage stock market investment. It is also highlighted that the more people are aware of and use technology (e.g., mobile technology), the more they are inclined to invest (Fatima & Chakraborty, 2025). Bucher-Koenen et al. (2025) found that, alongside external factors, intrinsic factors drive stock market participation, as individuals can only make better use of external opportunities when they are internally motivated.

One of the most influential internal and personal factors is financial literacy, which is strongly related to investment intentions and behaviors (Alqam & Hamshari, 2024). Financial literacy is also considered an important predictor of investment behaviors, including stock market participation (Ameer & Khan, 2020; Bucher-Koenen et al., 2021; Sapiri & Awaluddin, 2023). Therefore, we propose that financial literacy is an important predictor of stock market participation in Oman. However, the financial literacy score for Omanis is 10.5, which is lower than the OECD average (Mirzaei & Buer, 2022). Therefore, the proposed relationship needs empirical testing. The study is important because the Omani government has begun valuing the role of financial literacy and embedded it in Vision 2040. Although financial literacy has two domains

(objective and subjective financial literacy), objective financial literacy is valued because it provides a more accurate picture of literacy through bias-free evaluation (Xin et al., 2024). Therefore, this study first aims to understand Omani youth's objective financial literacy level and their stock market participation.

However, some recent studies suggest that personal factors may influence financial literacy and stock market participation (Mirzaei & Buer, 2022). For instance, age, education, family wealth, occupation, and social groups (Changwony et al., 2015; Gomes & Smirnova, 2021; Menkhoff & Westermann, 2025; Vaarmets et al., 2019). A literature review shows that empirical research on this topic remains scant, especially in Oman. Against this backdrop, the current study aims to identify Omanis' level of financial literacy and stock market participation.

This study also considers the role of financial wellbeing in predicting stock market participation. Financial wellbeing is important as it is a major element of overall wellbeing in life (Netemeyer et al., 2018). Past literature has highlighted that financial wellbeing is instrumental for favorable financial outcomes (e.g., Selvia et al., 2021). Recent studies have highlighted that investment behavior requires financial stability and support, which are present when financial wellbeing is present (Alqam & Hamshari, 2024; Sorgente & Lanz, 2019). Recent meta-analytic findings by Santini et al. (2025) highlighted that financial wellbeing results from positive individual factors and can also lead to positive overall life outcomes. Therefore, studying financial wellbeing is imperative, as it drives overall life satisfaction and wellbeing.

Financial wellbeing is another factor that may influence investment decisions. As an important component of overall wellbeing, it reflects individuals' ability to meet their financial needs and maintain financial security (Netemeyer et al., 2018). Previous studies have linked financial well-being to favorable financial outcomes and investment behavior (Selvia et al., 2021; Alqam & Hamshari, 2024; Sorgente & Lanz, 2019). Santini et al. (2025) further highlighted its relationship with individual characteristics and broader life outcomes. Research also suggests that personal, environmental, and institutional factors shape financial well-being, with financial literacy identified as an important

predictor (Hernandez-Perez & Cruz Rambaud, 2025; Lusardi & Streeter, 2023; Nanda & Banerjee, 2021). Nevertheless, evidence on the relationship between financial literacy, financial well-being, and stock market participation in Oman remains limited.

This study examines financial literacy and stock market participation in Oman, considering demographic differences and the role of financial well-being in their relationship. By examining these factors together, the study contributes empirical evidence from an Omani sample and offers insights into the relationship between financial knowledge, financial well-being, and investment behaviour.

LITERATURE REVIEW

Existing literature has highlighted the value of stock market participation and its relationship with financial literacy and financial well-being. However, it has given limited attention to differences in these factors across demographic groups. Previous studies have highlighted the role of demographic variables in stock market participation. For instance, Menkhoff and Westermann (2025) identified that age, education, family wealth, and risk-taking propensity influence the likelihood of stock market participation. In their empirical study, Gomes and Smirnova (2021) observed that the likelihood of investment is higher at younger ages, levels off in middle age, and declines at older ages.

Vaarmets et al. (2019) identified that occupation influences individuals' interest in investments and stocks. Ameriks and Zeldes (2004) highlighted that investors' age largely influences investment decisions, as younger individuals may be more willing to take risks but have less experience identifying them. Changwony et al. (2015) highlighted that social groups influence individuals' motivation to invest and their investment choices. Christiansen et al. (2008) further argued that education is another important predictor of stock market participation, as economics and business education increases individuals' understanding of financial markets and encourages participation.

Family background also matters, as families with higher levels of financial literacy tend to make more investments, including stock market participation (van Rooij et al., 2011). Cole and Shastry (2014) further highlighted that financial

education improves individuals' understanding of markets, finance and the economy, encouraging them to pay closer attention to their financial future and invest to achieve financial wellbeing. Hong et al. (2004) emphasized the role of location and background in financial choices, literacy and investments. They identified that individuals living in cities have more investment opportunities and greater access to financial markets, which may encourage stock market participation.

Taken together, these studies suggest that demographic factors (e.g., age, education, family background, and occupation) are associated with financial literacy, financial wellbeing, and stock market participation. Accordingly, the following hypothesis is proposed:

H1: Financial literacy, financial wellbeing, and stock market participation differ significantly across demographic groups.

According to Remund (2010), financial literacy refers to one's understanding of financial concepts and ability to make financial decisions considering economic and life circumstances. Previous studies have shown that financial literacy predicts financial behavior (Sivaramakrishnan et al., 2017; Zhao & Zhang, 2020). Financial literacy encompasses two major dimensions: subjective and objective financial literacy (Nejad & Javid, 2018). The former reflects individuals' confidence in their financial abilities (Alba & Hutchinson, 2000), while the latter refers to their understanding of financial instruments, principles, and concepts (Lusardi & Mitchell, 2014). Although both dimensions matter (e.g., Zhao & Zhang, 2021), objective financial literacy more directly assesses financial knowledge and is less affected by self-reporting bias (Xin et al., 2024).

Therefore, this study uses objective financial literacy to assess individuals' financial knowledge. Previous research has identified objective financial literacy as an important determinant of investment behavior (Kim et al., 2019), including stock market participation (Akhtar & Das, 2019). Higher objective financial literacy has also been associated with a greater propensity to invest in risky assets (Liao et al., 2017), including mutual funds (Chu et al., 2017) and stocks (Thomas & Spataro, 2018). Based on these findings, this study examines the relationship between objective financial literacy and stock market participation in Oman through the following hypothesis:

H2: Objective financial literacy is positively related to stock market participation.

Previous research has also linked stock market participation to financial wellbeing, defined as a state in which individuals feel financially secure, have financial freedom, and believe they can meet their current and future financial needs and achieve desired outcomes (Netemeyer et al., 2018). Financial wellbeing may influence individuals' ability to meet these needs and contribute to overall life satisfaction. Under such circumstances, individuals are more likely to plan and manage their financial resources, including savings and investments (Alqam & Hamshari, 2024). Financial wellbeing may also strengthen their ability to manage resources effectively (Lusardi & Mitchell, 2014).

Financial wellbeing enables individuals to manage their resources during difficult times and stressful situations (Naami et al., 2023). This may stem from the sense of financial protection and security associated with financial wellbeing (Cannon et al., 2024). Handranata et al. (2022) also observed a relationship between financial wellbeing and stock market investment, including during crises such as the COVID-19 pandemic. Investments can help protect financial health (Sriram et al., 2024) by increasing the future value of invested funds.

Bucher-Koenen et al. (2023) identified a relationship between stock market participation and financial wellbeing, suggesting that investment opportunities and financial security are closely connected. Furthermore, higher levels of financial wellbeing may encourage individuals to invest in stocks. Parvin et al. (2026) also highlighted the role of financial wellbeing in stock market participation, suggesting that individuals who are more satisfied with their financial situation may be more inclined to invest. Based on these findings, the following hypothesis is proposed:

H3: Financial wellbeing is positively related to stock market participation.

Taken together, the reviewed studies suggest that financial literacy and financial wellbeing are associated with stock market participation, while demographic characteristics may account for differences across individuals. This study further examines these relationships using empirical data from Oman.

RESEARCH METHODS

The research uses a quantitative approach with a one-step (cross-sectional) design. The working-age population of Oman (15-64 years) was considered the general population. According to Al-Jilani (2026), the number of Omani citizens is 3.04 million (excluding foreign citizens), of which 59.1%, or approximately 1.8 million people, belong to this age group. To determine the required sample size, the Yamane formula (Yamane, 1967) was used by formula (1):

$$n = N / (1 + Ne^2) \quad (1)$$

where:

n – the required sample size;

N – the size of the population;

e – the error term.

With a permissible sampling error of 5% and a population size of approximately 1.8 million people, the calculation using formula (1) showed that the required sample size is approximately 400 respondents. To further assess the minimum sample size, considering a higher level of confidence, Cochran's formula (Cochran, 1977) was used, as presented below in formula (2):

$$n_0 = \frac{Z^2 \cdot p \cdot (1-p)}{e^2} \quad (2)$$

where:

n₀ – the estimated sample size;

Z – the critical value of the standard normal distribution corresponding to the selected confidence level;

p – the estimated proportion of the population possessing the trait under study;

e – the maximum allowable sampling error.

The calculation used a 99% confidence level, which corresponds to $Z = 2.576$. Because no preliminary information was available about the distribution of the studied characteristics in the population, p was set to 0.5. This approach makes it possible to obtain the maximum calculated sample size for the given parameters. The permissible error was maintained at 5% ($e = 0.05$). Substituting these

values into formula (2) yields 663.58, which, when rounded up, amounts to 664 respondents. Thus, the minimum sample size for the study was set at 664 participants.

Primary data were collected between February and June 2026 through an online survey conducted in major cities of Oman, including Muscat, Salalah, and Sohar. The survey targeted individuals aged 18 and above who participated in household financial decision-making and were familiar with basic financial concepts. A total of 1,000 questionnaires were distributed, and 786 responses were received. After screening the responses against the inclusion criteria, 739 valid questionnaires were retained for further analysis. The final sample exceeded the minimum sample size of 664 respondents calculated using Cochran's formula (2).

Convenience and referral sampling techniques were employed to recruit respondents. These methods were selected mainly because a complete sampling frame was unavailable and because they offered practical advantages in time and resources (Jager et al., 2017; Etikan et al., 2016). To obtain a more diverse sample, the researchers recruited respondents across different demographic categories, including gender, age, occupation, marital status, household financial decision-making role, and family type. Nevertheless, the non-probability nature of the sampling procedure should be considered when interpreting the findings and generalising them to the wider Omani population.

The measurement instruments were adapted from previous studies. Financial literacy was assessed using three items adopted from Yang et al. (2023), covering respondents' understanding of interest rates, inflation, and financial risk. Each question offered multiple response options, with correct answers coded as 1 and incorrect or other responses coded as 0.

Financial wellbeing was measured using the four-item scale developed by Handranata et al. (2022). Responses were converted to binary values, with "Agree" and "Strongly agree" coded as 1 and "Disagree", "Strongly disagree", and missing responses coded as 0. Jeong and Lee (2016) discussed a similar approach to dichotomizing response scales.

Stock market participation was measured using a binary question: "Have you invested in the stock market, either directly or through a fund that invests

in stocks?" Responses were coded as 1 for "Yes" and 0 for "No". The question was adapted from Zhao and Zhang (2021).

Data analysis was carried out in three stages.

(1) First, descriptive statistics were calculated to examine the sample's demographic composition and the distribution of financial literacy, financial wellbeing, and stock market participation. Pearson's chi-square (χ^2) tests were applied to assess associations between demographic characteristics and the three variables, providing the basis for testing H1.

(2) Second, hierarchical binary logistic regression was employed to examine the relationships between financial literacy, financial wellbeing, and stock market participation. The explanatory variables were introduced sequentially. Model 1 included demographic characteristics as control variables, Model 2 additionally incorporated financial literacy, and Model 3 introduced financial wellbeing. This procedure allowed us to examine each predictor's contribution while controlling for demographic differences, providing evidence to test H2 and H3. Model fit and improvements across successive models were assessed using the -2 log-likelihood statistic and McFadden's pseudo- R^2 .

(3) Third, an additional mediation analysis was performed using the Karlson–Holm–Breen (KHB) method, which allows effects to be decomposed in nonlinear regression models. This analysis examined the potential mediating role of financial wellbeing in the relationship between the three components of financial literacy (interest rates, inflation, and risk) and stock market participation. Total, direct, and indirect effects were estimated, together with their statistical significance.

RESULTS

This section presents the results of an analysis of financial literacy, financial well-being, and Omani participation in the stock market. In the first stage, we examined respondents' socio-demographic characteristics and differences in financial knowledge, including understanding of interest rates, inflation, and financial risk. The distribution of correct and incorrect answers, by respondents' socio-demographic characteristics, makes it possible to identify differences in financial literacy between population groups (Table 1).

Table 1. Demographic characteristics and distribution of financial literacy responses (N = 739)

Variable	Sample (%)	Financial literacy					
		Interest		Inflation		Risk	
		Know (n=347)	Don't know (n=392)	Know (n=301)	Don't know (n=438)	Know (n=263)	Don't know (n=476)
Gender		X ² =18.65***		X ² =16.92***		X ² =17.52***	
Male	53.56	83.59	16.41	54.58	42.06	35.69	62.74
Female	39.86	13.42	79.63	42.06	54.58	62.74	35.69
Not specified	6.58	2.99	3.96	3.36	3.36	1.57	1.57
Age		X ² =123.55**		X ² =111.69**		X ² =96.74***	
<20 years	18.98	22.65	21.37	18.96	12.56	15.45	22.69
21-30 years	29.65	31.89	19.52	23.25	21.12	23.67	20.58
31-40 years	14.58	26.71	13.85	19.52	19.45	19.69	25.69
41-50 years	16.85	14.39	12.68	23.63	26.85	29.55	18.43
>50 years	19.94	4.36	32.58	14.64	20.02	11.64	12.61
Profession		X ² =45.32**		X ² =0.568		X ² =66.98***	
Student	34.58	19.3	35.69	20.18	25.69	21.75	9.25
Job holder	29.38	34.09	12.68	23.69	18.58	53.75	21.39
Entrepreneur	7.65	27.98	23.75	26.58	26.86	12.65	33.59
Graduated job seeker	28.39	18.63	27.88	29.55	28.87	11.85	35.77
Marital Status		X ² =3.62		X ² =5.85		X ² =7.90**	
Single	47.54	48.35	42.17	42.65	47.43	38.65	42.15
Married	33.83	43.75	51.31	48.9	50.68	43.55	49.52
Not specified	18.63	7.9	6.52	8.45	1.89	17.8	8.33
Decision-making role		X ² =79.55**		X ² =98.90**		X ² =80.74**	
Dependent	53.68	12.35	57.63	18.69	23.75	18.74	25.45
Independent	23.57	31.68	18.69	23.55	18.69	22.65	20.67
Make major family decisions	12.69	31.68	19.25	32.32	33.25	31.85	28.62
Only participate in family decisions	10.06	24.29	4.43	25.44	24.31	26.76	25.26
Family type		X ² =89.25***		X ² =75.69**		X ² =6.69	
Nuclear family	12.25	19.63	32.69	10.35	35.69	21.58	25.12
Single-parent family	8.2	11.58	25.63	19.45	25.74	23.9	22.25
Extended family	45.35	36.85	18.25	32.65	12.45	20.18	22.18
Blended family	28.2	21.74	18.65	33.87	22.85	19.65	19.74
Not specified	6	10.2	4.78	3.68	3.27	14.69	10.71

χ^2 – Pearson's chi-square statistic; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Percentages are reported by response category

Note: compiled by the authors.

Table 1 reveals the demographic profile (gender, age, profession, marital status, decision-making roles, and family type) and descriptive statistics (financial literacy – inflation, interest, and risk). The results show that most respondents were male (53.56%), aged 30 years or younger (48.63%), students (34%), single (48%), dependent (54%), and living in an extended family (45%). Financial literacy was low to moderate in the sample; 47% responded correctly to questions of interest, 41% to questions of inflation, and 36% to questions of risk. These results align with Mirzaei and Buer (2022),

who found that financial literacy was low in Oman and that people with more knowledge had higher savings and investment intentions.

The table also shows that gender is significantly associated with financial literacy elements (Interest, Inflation, and Risk). The male sample showed higher financial literacy in interest and inflation. In contrast, the female sample was better at understanding risk, showing a significant imbalance between male and female samples ($X^2 = 16.92$ – 31.77 , $p < .001$, $p < .0001$). In addition, individuals under 30 are more knowledgeable about interest ($X^2 = 123.55$ **),

inflation ($X^2 = 111.69^{**}$), and risk ($X^2 = 96.74^{***}$). These results support previous literature, e.g., Zhao and Zhang (2021), who found that younger individuals behave differently in financial matters than other age brackets. These results also align with Mirzaei and Buer (2022), who found that the Omani population has different levels of financial literacy by gender, age, and education.

Respondents' professions showed mixed results across samples. Financial literacy differed significantly by profession (interest and risk factors, $X^2=45.32^*$ and $X^2=66.98^{***}$), with job holders showing a higher level of understanding of interest and risk. Entrepreneurs and students displayed the lowest level of understanding of the elements of financial literacy. Marital status was significantly associated with financial wellbeing ($X^2= 6.63$, $p < 0.05$), but not with stock market participation ($X^2= 4.56$, $p > 0.05$). Married individuals were more knowledgeable about financial risks ($X^2=7.90^{**}$).

Individuals' decision-making roles were also significantly associated with interest ($X^2=79.55^{**}$), inflation ($X^2=98.90^{**}$), and risk ($X^2=80.74^{**}$), with independent individuals or those who contributed to family decisions showing higher financial literacy (understanding of interest, inflation, and risk).

The results also show significant differences in family understanding of interest ($X^2=89.25^{***}$), inflation ($X^2=75.69^{***}$), and financial literacy ($X^2=42.96^{**}$). Members of the extended or blended family have a better understanding of interest and inflation. Family type did not affect understanding of the risk element. The results show that gender, age, profession, decision-making roles, and family type are the main factors affecting financial literacy. Marital status was significantly associated only with risk-related knowledge. Table 2 presents demographic results related to financial well-being and stock market participation.

Table 2. Descriptive statistics for financial well-being and stock market participation

Variable	Financial well-being: High (n = 459)	Financial wellbeing: Low (n = 280)	Stock market participation: Yes (n = 189)	Stock market participation: No (n = 450)
Gender	$X^2= 12.56^{**}$		$X^2=12.56$	
Male	75.68	24.32	76.25	23.75
Female	81.36	18.64	22.68	72.82
Not to specify	1.03	2.36	1.07	3.43
Age	$X^2=9.79$		$X^2=124.05^{***}$	
<20 years	20.18	18.48	2.05	1.05
21-30 years	19.65	21.58	14.36	19.52
31-40 years	18.2	19.85	38.65	28.95
41-50 years	23.65	23.62	29.78	35.62
>50 years	18.32	16.47	15.16	14.86
Profession	$X^2=75.09^{**}$		$X^2=50.81^{***}$	
Student	11.25	42.57	9.67	21.59
Job holder	32.35	16.63	51.28	19.58
Entrepreneur	42.25	9.54	15.38	13.68
Graduated job seeker	14.15	31.26	23.67	45.15
Marital Status	$X^2=6.63$		$X^2=4.56$	
Single	51.09	48.91	46.57	40.06
Married	48.91	51.09	41.92	51.35
Not to specify	0	0	11.51	8.59
Decision-making role	$X^2=15.23^*$		$X^2=81.35^{**}$	
Dependent	17.18	20.32	24.5	51.05
Independent	21.39	23.65	31.68	23.68
Make major family decisions	39.58	36.81	24.76	12.59
Only participate in family decisions	21.85	19.22	19.06	12.68
Family type	$X^2=42.96^{**}$		$X^2=16.95^{***}$	
Nuclear family	12.59	33.61	18.36	23.25

Single parent family	18.56	29.6	12.35	19.62
Extended family	32.74	19.65	36.58	28.65
Blended family	31.56	12.59	18.54	22.15
Not specified	4.55	4.55	14.17	6.33
χ^2 – Pearson's chi-square statistic; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Percentages are reported by response category				

Note: compiled by the authors.

Table 2 presents descriptive results for financial well-being and stock market participation. Financial well-being was classified as high for 62% of respondents, with 62% reporting they felt financially well. The table reveals that only 26% of the respondents invested in the stock market (either directly or indirectly). These results reveal high financial well-being and low stock market participation in the sample. Gender was also significantly associated with stock market participation, with males more inclined to participate.

The results show that stock market participation was higher in the 31-50 age group ($X^2=124.05^{**}$), and well-being did not differ across age groups. Profession showed mixed results across samples: well-being ($X^2=75.09^{***}$) and stock market participation ($X^2=50.81^{***}$) differed across samples, with job holders showing higher financial well-being and stock market participation. Entrepreneurs and students had low stock market participation, while students and graduate job seekers had the lowest financial well-being. Marital status did not differ in financial well-being and stock market participation (i.e., $X^2=6.63$ and $X^2=4.56$, respectively). Individuals' decision-

making roles were also significantly associated with financial well-being ($X^2=15.23^*$) and stock market participation ($X^2=81.35^{**}$), with individuals who were independent or contributed to family decisions showing greater intent to participate in the stock market through investment.

The table also presents the effects of family type on financial well-being and stock market participation. The results reveal a significant difference in stock market participation by family type ($X^2=76.95^{***}$). Members of extended or blended families also have higher levels of financial well-being, while members of extended families participate in the stock market. Family type did not affect understanding of the risk element. The results show that gender, age, profession, decision-making roles, and family type are the main factors affecting financial well-being and stock market participation. In contrast, marital status does not affect financial literacy or stock market participation. Based on Tables 1 and 2, the results support H1.

The effects of demographic variables and predictors (financial literacy and financial well-being) are further tested through hierarchical logistic regression as shown in Table 3.

Table 3. Hierarchical binary logistic regression predicting stock market participation

Variable	Stock Market Participation					
	Model-1		Model-2		Model-3	
	Exp (p)	S.E.	Exp (p)	S.E.	Exp (p)	S.E.
Intercept	3.28	0.71	0.63	0.79	0.35	0.85
Gender (Ref: Female)						
Female	0.38**	0.41	0.42**	0.39	0.45**	0.31
Not to specify	0.09	0.63	0.11	0.62	0.09	0.54
Age (Ref: <20 years)						
21-30 years	0.12	0.25	0.14	0.39	0.16	0.29
31-40 years	0.48**	0.37	0.46**	0.35	0.44**	0.30
41-50 years	0.32**	0.54	0.30**	0.52	0.28**	0.33
>50 years	0.08	0.56	0.07	0.63	0.06	0.67
Profession (Ref: Student)						
Job holder	0.42**	0.23	0.48**	0.19	0.52**	0.18

Entrepreneur	0.21**	0.32	0.23**	0.35	0.29**	0.21
Graduated job seeker	0.08	0.41	0.07	0.39	0.10	0.38
Marital status (Ref: Single)						
Married	0.09	0.68	0.19**	0.5	0.2***	0.37
Not to specify	0.02	0.72	0.05	0.69	0.04	0.77
Decision making role (Ref: Dependent)						
Independent	0.15**	0.54	0.28***	0.28	0.32***	0.35
Make major family decisions	0.22**	0.31	0.29**	0.25	0.34***	0.29
Only participate in family decisions	0.06	0.63	0.09	0.59	0.09	0.57
Family type (Ref: Nuclear family)						
Single parent family	0.09	0.65	0.08	0.69	0.09*	0.42
Extended family	0.26**	0.28	0.29**	0.25	0.32**	0.28
Blended family	0.25**	0.36	0.26**	0.29	0.28**	0.25
Not to specify	0.07	0.68	-0.06	0.54	-0.05	0.56
Financial Literacy			1.42**	0.2	1.33**	0.29
Financial wellbeing					1.25***	0.3
-2 log likelihood	669.25		628.69		581.42	
Δ -2 log likelihood	-		40.56		47.27	
McFadden R ²	.3219		.3495		.3927	

Note: compiled by the authors

Table 3 presents the results of hierarchical logistic regression. McFadden's pseudo-R² increased from 0.3219 in Model 1 to 0.3927 in Model 3, with the latter showing the highest reported explanatory power (McFadden, 1977). The -2 log-likelihood decreased from 669.25 to 628.69 and subsequently to 581.42. The corresponding reductions of 40.56 and 47.27 indicate improved model fit after including financial literacy (Model 2) and financial wellbeing (Model 3), respectively.

The male sample is significantly ($p < .01$) associated with participation in the stock market across all three models. The odds ratio of .38 to .45 indicates males have higher stock market participation interest when compared with females. The effects slightly strengthen after the inclusion of financial literacy and financial wellbeing in the models, highlighting that these variables even influence stock market participation after controlling for gender. While looking at the age groups, it is evident that respondents from 31-40 years of age are more inclined to invest in stock markets (odd ratio of 0.44-0.48, $p < .01$) followed by the age group of 41-50 (odd ratio of .28-.32, $p < .01$). Similarly, when we look at the professional groups of respondents, it is evident that job holders and entrepreneurs were more inclined to invest in stock markets (odd ratios .42-.52, $p < .01$ for job holders; odd ratios .21-.29, $p < .01$ for entrepreneurs).

Regarding marital status, married individuals

are more inclined to invest (odds ratios .19- .20, $p < .01$ and $p < .001$, respectively) when literacy and financial wellbeing are added (model-2 and model-3). This suggests that married individuals tend to participate in stock markets because of pooled resources, shared financial decisions, and financial stability. Independent (odds ratio .15-.32, $p < .001$) and major family decision makers (odds ratio .22-.34, $p < .01$ -.001) are significantly associated with participation in stock markets, with major family decision makers being more inclined. Those who participate only in family decisions are less likely to invest in stocks. Participants from extended (odds ratio .26-.32, $p < .01$) and blended families (odds ratio .25-.28, $p < .01$) are more likely to participate in stock investments. Single-parent families are interested in investing in stock markets only when they have financial wellbeing ($p < .05$, model-3).

Financial literacy is positively associated with participation in the stock market ($p < .01$) in both model-2 and model-3; a one-unit increase in financial literacy was associated with 33–42% higher odds of stock market participation. The results show that financial literacy is a significant predictor of stock market participation; H2 is supported. After adding financial wellbeing in model 3, it is further evident that financial wellbeing is positively associated with participation in the stock market ($p < .001$; with a one-unit increase in financial wellbeing, the odds

of stock market participation were 25% higher), supporting H3.

After including financial wellbeing, the odds ratio for financial literacy decreased from 1.42 to 1.33, suggesting a possible mediating role of financial wellbeing. To examine this relationship

further, an additional mediation analysis was conducted using the Karlson–Holm–Breen (KHB) method, which accounts for rescaling differences in nested nonlinear probability models (Karlson & Holm, 2011). Table 4 presents the results.

Table 4. Mediation analysis using the KHB method

Financial literacy components and effects	Coefficient	S.E.	p-value
Interest			
Reduced model (without mediator)	0.129	0.049	0.012
Full model (with mediator)	0.118	0.053	0.049
Difference (indirect effect)	0.011	0.004	0.020
Inflation			
Reduced model (without mediator)	0.391	0.100	less than 0.001
Full model (with mediator)	0.328	0.103	0.001
Difference (indirect effect)	0.063	0.017	less than 0.001
Risk			
Reduced model (without mediator)	0.254	0.028	0.001

Note: compiled by the authors

Table 4 presents the results, where the total effect comes from the coefficient of the reduced model (model-2, without mediator), while the full model (model-3, with mediator) estimates the direct effects. The indirect effects are based on differences between the total and direct effect coefficients. The table shows that all direct (0.118, 0.328, and 0.179) and total effects (0.129, 0.391, and 0.254) are significant. The coefficient differences (indirect effects) are also significant (0.011, 0.063, and 0.075, respectively), supporting the partial mediation mechanisms.

CONCLUSION

The study identified the characteristics of financial literacy, financial well-being, and Omani participation in the stock market. The survey results from 739 respondents indicate a relatively low level of financial knowledge: 47% of participants answered correctly on questions about interest rates, 41% about inflation, and 36% about financial risk. At the same time, only 26% of the respondents reported participating in the stock market, while 62% rated their financial well-being positively. This discrepancy deserves attention, as a sense of financial stability is not always accompanied by sufficient understanding of financial instruments and investment opportunities. Mirzaei and Buer

(2022) also pointed to insufficient financial literacy in Oman.

The analysis showed that financial knowledge and investment behavior vary depending on socio-demographic characteristics. The most noticeable differences relate to age, gender, professional status, role in family decision-making, and family type. The regression results also indicate a positive relationship between financial literacy and financial well-being and stock market participation. Additional mediation analysis suggests that financial well-being may act as an intermediate link between financial knowledge and investment behavior. However, the nature of this relationship requires further study.

Overall, this research provides insights into the relationship among financial literacy, financial well-being, and stock market participation in Oman. It is concluded that stock market participation is influenced by financial literacy, financial wellbeing, and demographic characteristics. Demographic variables such as gender, age, employment status, decision-making autonomy, and family structure emerge as important considerations when studying financial knowledge and behavior in Oman. The results suggest that financial outcomes should be addressed through both cognitive (e.g., financial knowledge and literacy) and affective factors (attitude, emotional disposition, and confidence).

The findings highlight that financial literacy and participation in stocks are low, but financial well-being is considered moderate to high in Oman. These results could be investigated further by considering the factors that explain the underlying reasons for such findings. Theoretically, researchers can identify new research directions and design future studies that could further the literature on financial literacy, financial wellbeing, and investment in stocks. Practically, these results are useful for policymakers, educators, and financial institutions, as they can draw their interventional mechanisms from the given findings. A set of comprehensive strategies can promote financial literacy and stock market investment by further strengthening financial well-being.

Several limitations should be acknowledged. The use of convenience and referral sampling, together with the concentration of respondents in major cities, limits the generalisability of the findings to the wider Omani population. Moreover, the cross-sectional design does not allow causal relationships to be established. Future research could employ more representative samples, examine changes in financial behaviour over time, and consider additional factors such as household income, digital financial skills, and family financial socialisation.

Overall, improving stock market participation in Oman requires attention not only to financial knowledge but also to the conditions under which individuals make investment decisions. Combining financial education with accessible financial services may help households make more informed choices and strengthen their long-term financial well-being.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: IA; research design: IA and ZA; data collection: IA, ZA and HK; analysis and interpretation: IA, ZA and HK; writing and draft preparation: IA, ZA, HK; Supervision: IA; correction of article: HK; proofread and finalization: ZA & HK. All authors have read and agreed to the published version of the manuscript.

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Macroeconomic Drivers of Inflation in a Commodity-Exporting Economy: Evidence from Kazakhstan

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ABSTRACT

Inflation remains a central macroeconomic challenge for emerging economies, as persistent price instability undermines economic growth, distorts income distribution, and weakens the effectiveness of monetary policy. This study aims to assess the relationships between inflation, the policy rate, the exchange rate, oil prices, and National Fund transfers in Kazakhstan using annual data for 2000–2025 and an Autoregressive Distributed Lag (ARDL) model. The initial data consist of annual time series for 2000–2025, including 26 observations for each indicator, compiled from statistics from the Bureau of National Statistics, the National Bank of Kazakhstan, the World Bank, and the Ministry of Finance of the Republic of Kazakhstan. Descriptive statistics, correlation analysis, the Dickey–Fuller test, and the ARDL autoregressive distributed lag model were used. The coefficient for the lagged exchange rate was -0.0733 ($p = 0.0274$), and for the current logarithm of the oil price, it was 6.9936 ($p = 0.0048$), while the current and lagged coefficients for the interest rate and the logarithm of National Fund transfers are statistically insignificant at the 5% level. The model is characterized by a determination coefficient of $R^2 = 0.6546$ and overall statistical significance ($F = 1.159$; $p = 0.0239$), however, the bounds test did not confirm the presence of a long-term relationship between the variables ($F = 2.4282$; $p = 0.3762$). These results contribute to a deeper understanding of the factors influencing inflation in Kazakhstan and can inform monetary and macroeconomic policy.

KEYWORDS: Inflation, Interest Rate, Refinancing Rate, Fiscal Strategy, Monetary Policy, Macroeconomics, Resource-Dependent Economy

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Макроэкономические факторы инфляции в сырьевой экспортно-ориентированной экономике: на примере Казахстана

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АННОТАЦИЯ

Инфляция остается одной из главных макроэкономических проблем для стран с формирующимся рынком, поскольку постоянная нестабильность цен подрывает экономический рост, искажает распределение доходов и снижает эффективность денежно-кредитной политики. Целью данного исследования является оценка взаимосвязи между инфляцией, учетной ставкой, обменным курсом, ценами на нефть и трансфертами в Национальный фонд в Казахстане с использованием годовых данных за 2000-2025 годы и модели авторегрессии с распределенным лагом (ARDL). Исходные данные представляют собой годовые временные ряды за 2000–2025 годы, включающие 26 наблюдений по каждому показателю, сформированные на основе статистики Бюро национальной статистики, Национального банка Казахстана, Всемирного банка и Министерства финансов Республики Казахстан. Использованы описательная статистика, корреляционный анализ, тест Дики–Фуллера, модель авторегрессии с распределёнными лагами ARDL. Коэффициент при валютном курсе с лагом составил $-0,0733$ ($p = 0,0274$), а при текущем логарифме цены нефти — $6,9936$ ($p = 0,0048$), тогда как текущие и лаговые коэффициенты процентной ставки и логарифма трансфертов Национального фонда по отдельности статистически незначимы на уровне 5%. Модель характеризуется коэффициентом детерминации $R^2 = 0,6546$ и общей статистической значимостью ($F = 3,159$; $p = 0,0239$), однако тест границ не подтвердил наличие долгосрочной связи между переменными ($F = 2,4282$; $p = 0,3762$). Полученные результаты способствуют более глубокому пониманию факторов инфляции в Казахстане и могут быть использованы при формировании денежно-кредитной и макроэкономической политики.

КЛЮЧЕВЫЕ СЛОВА: инфляция, процентная ставка, ставка рефинансирования, фискальная стратегия, денежно-кредитная политика, макроэкономика, ресурсозависимая экономика

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INTRODUCTION

Inflation is defined as a sustained increase in the general price level of goods and services in an economy, accompanied by a decline in the purchasing power of the national currency. In simple terms, inflation means the same amount of money can buy fewer goods and services over time. In Kazakhstan, inflation is officially measured using the Consumer Price Index (CPI).

Inflation is an important indicator of macroeconomic stability because persistent price increases reduce households' purchasing power, increase business uncertainty, and complicate long-term investment and economic planning. For Kazakhstan, inflation matters because the economy remains sensitive to external commodity prices and exchange rate movements. Since 2015, the National Bank of Kazakhstan has implemented an inflation-targeting regime combined with a floating exchange rate. The effectiveness of this framework depends not only on monetary policy but also on external shocks and the economy's structural characteristics.

Since independence, Kazakhstan has experienced considerable fluctuations in inflation. These changes have been driven by both domestic and external factors, including changes in global oil prices, exchange rate movements, domestic demand, and major external shocks. The decline in global oil prices in 2015, the COVID-19 pandemic in 2020–2021, and the geopolitical shock in 2022 were accompanied by significant changes in price dynamics. For a commodity-exporting economy such as Kazakhstan, oil prices matter because they affect export revenues, the exchange rate, fiscal revenues, and domestic economic activity.

The relationship between oil prices and inflation can operate through several channels. Changes in energy prices can directly affect consumer prices and production costs. Oil price movements can also influence the exchange rate by changing export revenues and foreign currency inflows. In addition, changes in oil revenues may affect domestic demand through fiscal policy and transfers from the National Fund. Therefore, oil prices may affect inflation beyond the direct impact of energy costs.

The concept of greenflation also emphasizes the relationship between changes in energy markets and price pressures. The transition toward a low-carbon economy may increase the costs of energy

production and carbon-intensive goods during periods of adjustment. For this study, however, this issue is considered only as broader context for understanding energy-related inflationary pressures. The empirical analysis focuses on global oil prices as the main external energy-related variable.

Previous studies of inflation in Kazakhstan have identified exchange rate movements, oil prices, monetary conditions, and external price shocks as important determinants of inflation. However, these factors may affect inflation differently across periods and methods. In particular, fiscal transfers from the National Fund represent an important feature of Kazakhstan's economic system because they provide a channel through which oil-related revenues can enter the domestic economy.

This study aims to assess the relationships between inflation, the policy rate, the exchange rate, oil prices, and National Fund transfers in Kazakhstan using annual data for 2000–2025 and an Autoregressive Distributed Lag (ARDL) model. The study uses the Augmented Dickey–Fuller (ADF) test to determine the integration properties of the variables and the ARDL bounds testing approach to examine the presence of a long-run relationship. The analysis also considers short-run dynamics and applies diagnostic and stability tests to assess the model's adequacy. The study examines monetary, external, and fiscal factors within a single empirical framework. Including National Fund transfers allows the study to assess whether this fiscal channel is associated with inflation alongside global oil prices, the exchange rate, and the policy interest rate.

LITERATURE REVIEW

Inflation is a key macroeconomic factor affecting purchasing power, economic stability, and long-term development. Economic literature explains inflation through several interconnected channels, including monetary conditions, exchange-rate movements, global commodity prices, expectations, and fiscal policy. The relative importance of these factors differs across countries and periods, particularly during episodes of large external shocks. For a small, open, commodity-exporting economy such as Kazakhstan, monetary policy, the exchange rate, global oil prices, and fiscal conditions are especially relevant because domestic price dynamics depend

on both internal policies and developments in international markets.

The monetary explanation of inflation has a strong theoretical foundation. Friedman and Schwartz (1963) associate sustained inflation with monetary expansion, while Friedman (1968) emphasized the role of inflation expectations and their importance for monetary policy. More recent empirical research generally confirms the relevance of monetary conditions but shows that their effects depend on the economic environment and the selected indicators. Ujkani and Gara (2023), using panel data for 40 countries, find a positive relationship between money supply growth and inflation. Acar and Orhan (2023), focusing on OECD economies during and after the COVID-19 pandemic, show that monetary and fiscal expansion was associated with stronger inflationary pressures. Although these studies use different samples and explanatory variables, they suggest that monetary factors remain an important part of inflation dynamics and should be considered together with other macroeconomic conditions.

The monetary transmission mechanism is particularly important for emerging economies, where policy-rate changes may affect inflation with a considerable lag. Evidence for Kazakhstan also suggests that the structure of the domestic economy influences this relationship. Hledik et al. (2018), using a semi-structural quarterly model, examine monetary-policy transmission in Kazakhstan and emphasize the role of external conditions and oil prices in shaping it. More recent evidence from Kazakhstan suggests that the interest-rate channel may be weak. Impavido (2025), using monthly data from August 2016 to February 2025, analyzes monetary conditions together with fiscal policy, inflation expectations, and external price pressures. The study finds that monetary policy has only partly contained domestic and external inflationary pressures and points to weaknesses in the interest-rate transmission mechanism. These findings suggest that the effect of monetary policy on inflation should be considered dynamically, not only through contemporaneous changes in the policy rate.

Exchange-rate movements represent another major source of inflation, especially in economies that depend heavily on imported consumer and intermediate goods. Currency depreciation can

raise the domestic price of imports and increase production costs, which may subsequently be transmitted to consumer prices. Taylor (2000) argues that the strength of exchange-rate pass-through depends partly on the inflation environment, while McCarthy (2007) provides empirical evidence that exchange-rate and import-price shocks affect domestic consumer prices. For oil-exporting CIS economies, Rahimov et al. (2017) examine Azerbaijan, Kazakhstan, and Russia using a VAR approach and find significant but incomplete exchange-rate pass-through. Their findings indicate that exchange rate changes affect inflation, although these changes are not immediately passed through in full to consumer prices.

Recent micro-level evidence strengthens this argument for Kazakhstan. Kim et al. (2024) examine exchange-rate pass-through using retail scanner data covering more than 1,400 consumer products. Unlike studies based on aggregate price indices, their approach allows a comparison of price responses between imported and domestically produced goods. Using local projections, the authors find substantial but incomplete exchange-rate pass-through, with approximately half of an exchange-rate shock transmitted to retail prices within one year. They also identify asymmetric and nonlinear responses to exchange-rate movements. The findings complement earlier macroeconomic evidence and indicate that the exchange-rate channel remains important for explaining inflation in Kazakhstan, although its magnitude may depend on the direction and size of currency movements.

A third group of studies focuses on global commodity and oil-price shocks. The theoretical and empirical literature shows that oil-price changes can affect inflation through energy and production costs, aggregate demand, and broader macroeconomic adjustments (Hamilton, 2003, 2009; Kilian, 2009). Recent studies have expanded this analysis in response to the major global disruptions of the 2020s. Kilian and Zhou (2023) examine how energy-price shocks transmit to inflation using a structural VAR approach, while Pan et al. (2024) provide evidence of asymmetric interdependence between global commodity prices and inflation. Abu Asab (2025) similarly identifies oil and food prices, together with supply-chain disruptions, as important supply-side drivers of inflation. Despite differences in samples and methods, these

studies show that commodity shocks can generate significant price pressures, while their magnitude and persistence depend on the economy's structure and the nature of the shock.

The oil-price channel is particularly important for Kazakhstan because oil is a major source of export and fiscal revenues. As a result, changes in global oil prices may influence domestic conditions through several mechanisms, not only through energy costs. Hasanov et al. (2017) examine oil-exporting CIS economies and show that oil-price movements are related to exchange-rate dynamics. Akhmedov (2019), focusing specifically on Kazakhstan and applying a VAR model, finds that world oil-price shocks affect several domestic macroeconomic indicators. These results indicate that changes in global oil markets can be transmitted to Kazakhstan through broader macroeconomic channels. At the same time, the literature does not provide uniform evidence on the magnitude or timing of the inflation response to oil-price changes, providing a basis for testing this relationship directly.

Fiscal policy constitutes the fourth channel considered in the literature. Expansionary fiscal measures may contribute to inflation by increasing aggregate demand, particularly when the supply response is limited. The relationship received renewed attention following the large fiscal interventions during the COVID-19 period. Acar and Orhan (2023) show that fiscal expansion, together with monetary measures, was associated with higher inflation in OECD economies. However, the effect of fiscal policy likely depends on the institutional structure of public finance, suggesting that general cross-country findings may not fully explain the experience of resource-exporting economies.

This issue is particularly relevant for Kazakhstan because the National Fund creates an institutional link between oil revenues and the state budget. Transfers from the Fund provide fiscal resources that can support government expenditure and domestic demand. Therefore, they represent a more specific fiscal mechanism than general measures such as total government expenditure or the overall fiscal balance. Recent Kazakhstan-specific research confirms the importance of broader fiscal conditions. Impavido (2025), for example, identifies fiscal policy as an important source of domestic inflationary pressure, while distinguishing

it from external and imported inflation. However, the study represents fiscal conditions through the broader fiscal stance rather than National Fund transfers as an independent explanatory variable. Consequently, its findings do not directly establish whether transfers themselves are associated with inflation after accounting for monetary, exchange-rate, and oil-price factors.

Other recent Kazakhstan-specific studies emphasize additional aspects of the inflation process. Imanbayev et al. (2024) consider both domestic and external sources of inflation, including imported inflation and changes in global commodity prices. Jarzhanov et al. (2024) focus on household inflation expectations and emphasize their importance for monetary-policy effectiveness under inflation targeting. These studies broaden the understanding of inflation in Kazakhstan by showing that observed price dynamics are shaped not only by conventional monetary variables but also by expectations and external conditions.

Atamanchuk et al. (2025) provide a broader regional perspective by examining inflation in the Caucasus and Central Asia using three complementary approaches: an augmented Phillips curve, panel VAR, and local projections. Rather than focusing on a single transmission channel, the study considers domestic demand conditions and inflation expectations alongside external factors, including exchange rates and global food and oil prices. The results indicate that external factors play a major role in regional inflation dynamics, although domestic factors also contribute. The authors also find a statistically significant effect of monetary policy and show that it can moderate the impact of external shocks. This regional evidence is useful for Kazakhstan because it demonstrates that inflation in Central Asian economies reflects the interaction of several domestic and external forces rather than a single dominant determinant.

Comparison of the existing literature reveals important differences in both methodology and variable selection. Studies based on VAR models generally focus on dynamic interactions and responses to exchange-rate or oil-price shocks (Akhmedov, 2019; Kilian & Zhou, 2023; Rahimov et al., 2017), while semi-structural models examine broader monetary transmission mechanisms (Hledik et al., 2018). More recent research employs Phillips-curve specifications and local projections

to distinguish domestic and external inflation drivers and assess the responses to specific shocks (Atamanchuk et al., 2025; Impavido, 2025; Kim et al., 2024). Despite methodological differences, the literature broadly indicates that inflation in Kazakhstan and comparable economies reflects a combination of monetary conditions, exchange-rate movements, global commodity shocks, and domestic fiscal factors. At the same time, differences in data frequency, sample periods, country coverage, and model specification lead to variation in the estimated magnitude and timing of these effects.

This comparison also identifies a more specific research gap. Previous studies have examined monetary transmission, exchange-rate pass-through, commodity-price shocks, inflation expectations, and broader fiscal conditions in Kazakhstan, but National Fund transfers have received limited attention as a separate inflation determinant. In particular, the reviewed literature does not directly estimate the relationship between National Fund transfers and inflation while simultaneously accounting for the monetary policy interest rate, the KZT/USD exchange rate, and global oil prices. Thus, the research gap does not imply that previous research has ignored fiscal policy or National Fund operations. Rather, it concerns the limited empirical evidence on National Fund transfers as a distinct fiscal variable within a joint dynamic specification of inflation determinants.

The explanatory variables in the present study follow directly from these four channels. The monetary policy interest rate represents monetary conditions, while the KZT/USD exchange rate captures exchange-rate pass-through. Brent crude oil prices represent external commodity shocks and Kazakhstan's exposure as an oil-exporting economy. National Fund transfers capture the specific fiscal mechanism through which accumulated oil revenues are transferred to the state budget. Other variables, including money supply, import prices, food prices, inflation expectations, the output gap, and broader government expenditure, may also influence inflation. Their exclusion does not imply that they are unimportant; the present study focuses on the four channels directly related to its research objectives.

The study therefore complements the existing literature by examining these monetary, exchange-

rate, commodity-price, and fiscal factors within a single dynamic framework for Kazakhstan from 2000 to 2025. The empirical analysis applies the ARDL approach and the bounds-testing procedure developed by Pesaran et al. (2001). The ARDL framework incorporates lagged responses and provides a formal test for a possible long-run relationship among variables with appropriate orders of integration. In this way, the study builds on previous research while placing particular emphasis on National Fund transfers as a separate fiscal variable.

Based on the theoretical arguments and empirical findings discussed above, the following hypotheses are proposed:

H1: The monetary policy interest rate significantly affects inflation in Kazakhstan.

H2: Exchange rate movements significantly affect inflation in Kazakhstan.

H3: Global oil prices significantly affect inflation in Kazakhstan.

H4: National Fund transfers significantly affect inflation in Kazakhstan.

METHODOLOGY

This study examines the macroeconomic determinants of inflation in Kazakhstan over the period 2000-2025, with particular attention to monetary, exchange rate, commodity price, and fiscal factors. Inflation is the dependent variable, while the monetary policy interest rate, KZT/USD exchange rate, Brent crude oil price, and National Fund transfers to the state budget are explanatory variables.

The empirical analysis proceeds in several stages. First, the dataset is constructed, and variables are transformed as needed. Second, the stationarity properties of the time series are examined using the ADF unit root test. Given the identified orders of integration, an ARDL model is estimated to be following the methodological framework of Pesaran and Shin (1999) and Pesaran et al. (2001). The ARDL bounds testing procedure is then applied to test for a long-run relationship among the variables. Finally, diagnostic and stability tests assess the model's adequacy and robustness.

Table 1 presents the variables used in the empirical analysis, their units of measurement, and data sources.

Table 1. Model variables and sources

Variable	Definition	Source
Inflation	Annual average inflation rate measured by the consumer price index (CPI), %	Bureau of National Statistics of Kazakhstan
Rate	Monetary policy interest rate, % per annum; official refinancing rate for 2000-2014 and NBK base rate for 2015-2025, measured at the end of the year	National Bank of Kazakhstan
FX	Annual average nominal exchange rate, KZT per USD	National Bank of Kazakhstan
lnOil	Natural logarithm of the annual average Brent crude oil price, measured in USD per barrel before transformation	World Bank Commodity Price Data (Pink Sheet)
ln Transfers	Natural logarithm of annual National Fund transfers to the state budget, measured in trillion KZT before transformation	Ministry of Finance of the Republic of Kazakhstan

Note: compiled by the authors based on Bureau of National Statistics (2025), World Bank (2025), National Bank (2025)

The choice of the ARDL framework is motivated by both the statistical properties of the data and the dynamic nature of inflation. Inflation may respond to monetary, exchange-rate, commodity-price, and fiscal shocks with different time lags rather than adjusting instantaneously. The ARDL framework incorporates current and lagged values of the dependent and explanatory variables in a single dynamic specification and provides a basis for distinguishing short-run dynamics from a potential long-run relationship.

The methodological foundation follows Pesaran and Shin (1999) and Pesaran et al. (2001). An important advantage of the ARDL bounds-testing approach is its applicability when the variables are integrated of different orders, $I(0)$ and $I(1)$, provided that none of the variables is integrated of order two, $I(2)$. This property is particularly relevant to the present study because the variables exhibit mixed orders of integration.

The empirical specification is also informed by previous studies that use ARDL-type models to examine inflation dynamics through monetary, exchange-rate, and commodity-price channels. For example, Anderl and Caporale (2023) employ a linear ARDL model as a benchmark for examining inflation in developed and emerging economies, incorporating the policy interest rate, exchange rate, and oil-price-related factors. Mirza et al. (2023) use a nonlinear ARDL framework to investigate exchange-rate pass-through and energy-price shocks in inflation-targeting economies. These studies demonstrate the usefulness of distributed-lag specifications for capturing delayed and potentially heterogeneous responses of domestic prices to monetary and external shocks.

This framework is particularly relevant for

Kazakhstan, where inflation dynamics may be influenced simultaneously by domestic monetary conditions and external factors associated with exchange-rate and commodity-price movements. This study builds on this empirical literature by jointly considering the monetary policy rate, the KZT/USD exchange rate, Brent oil prices, and National Fund transfers. Including National Fund transfers extends the specification by adding a fiscal factor alongside the monetary and external determinants of inflation.

The empirical analysis begins with descriptive statistics to summarize the main characteristics of the variables. The analysis then examines the time series' stationarity using the Augmented Dickey-Fuller (ADF) unit root test. The results indicate that inflation is stationary at level, $I(0)$, whereas the interest rate, exchange rate, logarithm of oil prices, and logarithm of National Fund transfers become stationary after first differencing, $I(1)$. None of the variables is integrated of order two, which satisfies an important prerequisite for applying the ARDL bounds-testing approach.

Given the relatively small annual sample of 26 observations, the maximum lag length is restricted to one to preserve degrees of freedom and reduce the risk of overparameterization. Within this restriction, the lag structure is selected using the Akaike Information Criterion (AIC), resulting in an ARDL (1,1,1,1,1) specification. The empirical model is expressed as follows (1):

$$\begin{aligned}
 INF_t = & \beta_0 + \beta_1 INF_{t-1} + \beta_2 Rate_t + \\
 & + \beta_3 Rate_{t-1} + \beta_4 FX_t + \beta_5 FX_{t-1} + \\
 & + \beta_6 \ln Oil_t + \beta_7 \ln Oil_{t-1} + \\
 & + \beta_8 \ln Transfers_t + \beta_9 \ln Transfers_{t-1}
 \end{aligned} \quad (1)$$

where:

INF_t – the inflation rate;

$Rate_t$ – the monetary policy interest rate;

FX_t – the KZT/USD exchange rate;

$\ln Oil_t$ – the natural logarithm of the Brent crude oil price;

$\ln Transfers_t$ – the natural logarithm of National Fund transfers;

ϵ_t – the error term;

t – the period;

$t-1$ – a one-period lag;

β_0 – the constant term;

$\beta_1, \dots, \beta_9$ – the estimated coefficients of the corresponding variables.

The ARDL bounds testing procedure proposed by Pesaran et al. (2001), building on the ARDL framework of Pesaran and Shin (1999), was used to test for the existence of a long-run relationship among the variables. The null hypothesis assumes no long-run level relationship, whereas the alternative hypothesis assumes one. The calculated F-statistics are compared with the lower $I(0)$ and upper $I(1)$ critical bounds. If the F-statistics exceed the upper bound, reject the null hypothesis; if it falls below the lower bound, you cannot reject the null hypothesis; and if it lies between the two bounds, the result is inconclusive. The bounds' testing approach is appropriate when the variables are a mixture of $I(0)$ and $I(1)$, provided that none is integrated of order two, $I(2)$.

Given the small annual sample of 26 observations, finite-sample considerations are particularly relevant. Narayan (2005) demonstrates

that critical values may differ in small samples and reports finite-sample critical values for sample sizes ranging from 30 to 80 observations. Since the present sample contains only 26 observations, these values are not applied mechanically but are considered when interpreting the bounds-test results cautiously.

The adequacy of the estimated model was examined using a set of diagnostic tests. The Breusch-Godfrey LM test tested for serial correlation, the Breusch-Pagan test assessed heteroskedasticity, and the Jarque-Bera test examined residual normality. The Recursive CUSUM and CUSUM of Squares (CUSUMSQ) tests evaluated the stability of the estimated parameters.

RESULTS

The analysis of the results begins with examining the dynamics of inflation and the interest rate in Kazakhstan for the period 2000–2025. During this period, the country's economy faced fluctuations in world oil prices, changes in the exchange rate, and external shocks. Comparing the two indicators makes it possible to identify periods of acceleration and deceleration of inflation, trace changes in the interest rate, and assess how well they coincided in time. This examination provides an initial understanding of the dynamics of the indicators before conducting econometric analysis, but on its own does not establish a causal relationship between them. The dynamics of inflation and interest rates are presented in Figure 1.

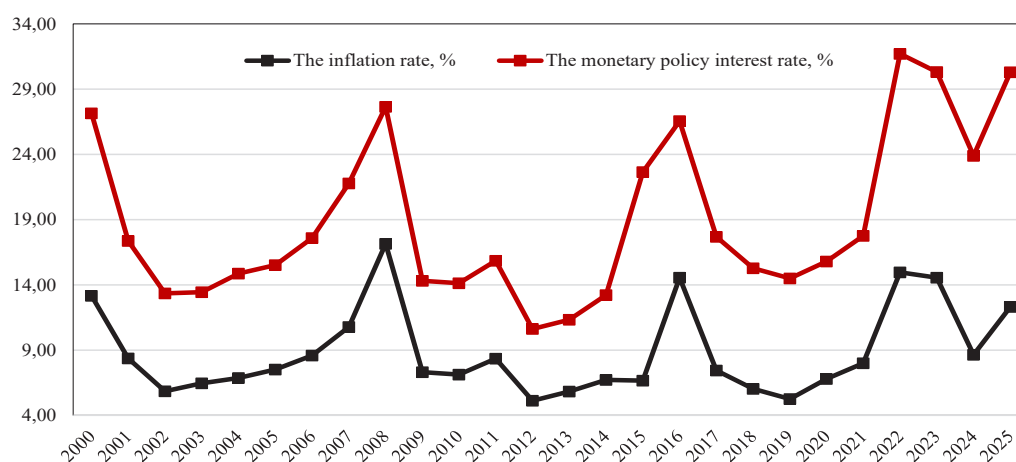


Figure 1. Dynamics of inflation and monetary policy rate in Kazakhstan for 2000–2025

Figure 1 illustrates several distinct episodes in the dynamics of inflation and the monetary policy interest rate in Kazakhstan over 2000–2025. One of the most pronounced inflationary episodes occurred in 2007–2008. Average annual inflation increased from approximately 10.8% in 2007 to about 17.0% in 2008. The National Bank of Kazakhstan reported that the acceleration of inflation in the second half of 2007 was driven primarily by a substantial increase in food prices. During the first half of 2008, Kazakhstan also faced a sharp rise in global prices for food, raw materials and other commodities. The subsequent easing of global commodity prices and weakening economic activity contributed to the moderation of inflationary pressures (National Bank of Kazakhstan, 2025).

A second important structural episode occurred in 2015–2016. In August 2015, Kazakhstan moved to an inflation-targeting monetary policy framework with a floating exchange rate. According to the National Bank, the transition took place against the background of falling global oil prices and depreciation pressures associated with weakening currencies of major trading partners. These

developments increased the importance of the exchange-rate channel for domestic price formation. The sharp tightening of monetary conditions visible in Figure 1 during this period therefore coincided with a major adjustment in Kazakhstan's monetary and exchange-rate framework (National Bank of Kazakhstan, 2025).

The next major inflationary cycle began after 2020. Inflationary pressures intensified during 2021 amid elevated external food prices, supply-demand imbalances in individual markets, disruptions in global and domestic supply chains, and persistently high inflation expectations. These factors created a difficult inflationary environment even before the additional external shocks that followed.

Before estimating the ARDL model, descriptive statistics were calculated to provide an overview of the distribution and variability of the variables included in the analysis. Table 2 reports the mean, median, minimum, maximum, and standard deviation of the model variables over the study period, with oil prices and National Fund transfers expressed in natural logarithms.

Table 2. Descriptive statistics of the variables

Variable	Mean	Median	Minimum	Maximum	Std_Dev
Inflation	8.662	7.365	5.118	17.148	3.360
Rate	10.163	9.125	5.500	18.000	3.640
FX	244.325	153.280	120.210	518.450	135.962
lnOil	4.052	4.079	2.954	4.741	0.492
lnTransfers	0.969	0.875	0.182	1.723	0.439

Note: compiled by the authors

The descriptive statistics indicate substantial variation in Kazakhstan's macroeconomic conditions over the sample period. Average inflation was 8.662%, with values ranging from 5.118% to 17.148%, while the policy rate averaged 10.163% and varied between 5.500% and 18.000%. The exchange rate averaged 244.325 KZT/USD, ranging from 120.210 to 518.450, with a standard deviation of 135.962. Its relatively large standard deviation (135.962) reflects substantial exchange-rate variation over the study period. The logarithmic oil-price variable had a mean of 4.052 and a standard deviation of 0.492, whereas lnTransfers averaged 0.969 with a standard deviation of 0.439. Overall, the descriptive statistics reveal considerable variation

in inflation, monetary conditions, the exchange rate, oil prices, and fiscal transfers over the period analyzed, providing an appropriate empirical basis for examining their dynamic relationships within the ARDL framework.

Following the descriptive analysis, Pearson correlation coefficients were calculated to provide a preliminary assessment of the relationships among the variables included in the model and to identify potential multicollinearity concerns. Table 3 presents the Pearson correlation matrix for inflation, the policy rate, the exchange rate, and the natural logarithms of oil prices and National Fund transfers.

Table 3. Correlation analysis

Variable	Inflation	Rate	FX	lnOil	lnTransfers
Inflation	1.000	0.522	0.167	0.055	0.274
Rate	0.522	1.000	0.644	0.051	0.703
FX	0.167	0.644	1.000	0.228	0.822
lnOil	0.055	0.051	0.228	1.000	-0.089
lnTransfers	0.274	0.703	0.822	-0.089	1.000

Note: compiled by the authors

The correlation analysis indicates a moderate positive and statistically significant association between inflation and the policy rate ($r = 0.522$, $p = 0.006$). In contrast, the contemporaneous correlations of inflation with FX ($r = 0.167$), lnOil ($r = 0.055$), and lnTransfers ($r = 0.274$) are relatively weak and statistically insignificant. Among the explanatory variables, the strongest positive correlation is observed between FX and lnTransfers ($r = 0.822$, $p < 0.001$). The policy rate is also positively correlated with FX ($r = 0.644$, $p < 0.001$) and lnTransfers ($r = 0.703$, $p < 0.001$).

Given the relatively high pairwise correlation between the exchange rate and National Fund transfers, an additional variance inflation factor (VIF) test was conducted to assess potential multicollinearity. The VIF values were 2.046 for the policy rate, 4.332 for the exchange rate, 1.413

for oil prices, and 4.835 for National Fund transfers. Since all values remained below the threshold of 5, the diagnostic results do not indicate severe multicollinearity among the explanatory variables. Nevertheless, the relatively high correlation between FX and lnTransfers should be taken into account when interpreting their individual coefficients. It should also be noted that the correlation coefficients represent contemporaneous pairwise associations and do not account for lagged adjustments or the dynamic structure of inflation. Therefore, the weak unconditional correlations between inflation and some explanatory variables do not preclude dynamic relationships in the subsequent ARDL analysis.

The dynamics of the variables included in the empirical model over the period 2000-2025 are presented in Figure 2.

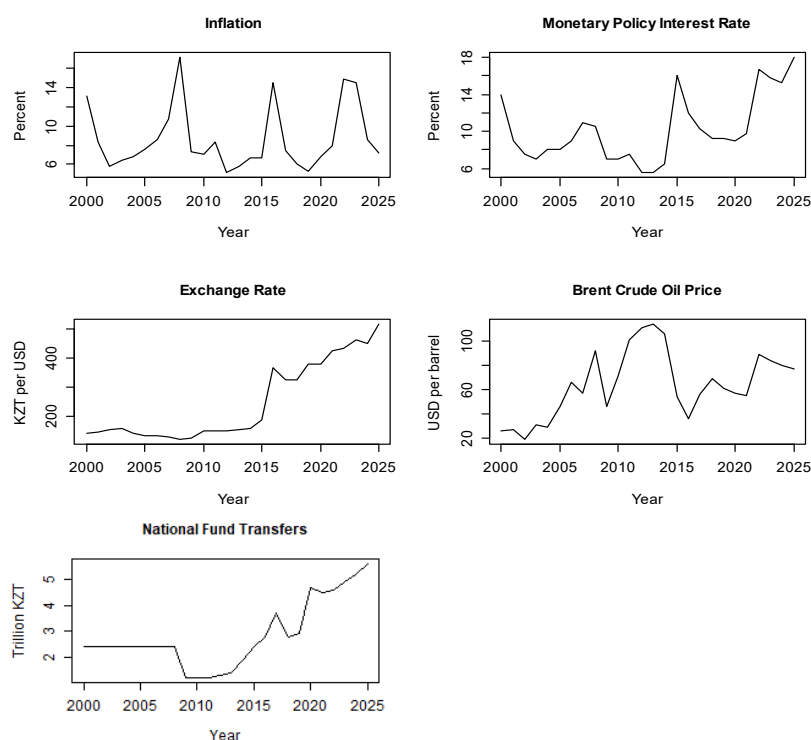


Figure 2. Time series dynamics of inflation, interest rate, exchange rate, oil prices and transfers for 2000-2025

The graphical representation provides an overview of changes in inflation, the monetary policy interest rate, the exchange rate, Brent crude oil prices, and National Fund transfers during the study period. Inflation and the monetary policy interest rate exhibit noticeable fluctuations, while the KZT/USD exchange rate shows a pronounced upward trend, particularly after 2014. Brent crude oil prices demonstrate substantial volatility, whereas

National Fund transfers vary considerably across the sample period and increase in the later years. These differences in the dynamics of the variables indicate the need to examine their time-series properties before estimating the ARDL model.

Before estimating the ARDL model, the integration orders of the variables were assessed using the ADF unit root test. The results are presented in Table 4.

Table 4. ADF unit root test results

Variable	ADF statistic (level)	5% critical value	ADF statistic (1st difference)	5% critical value	Integration order
Inflation	-3.5463	-3.00	-	-	I(0)
Rate	-1.4087	-2.93	-4.2301	-3.00	I(1)
FX	0.7615	-2.93	-3.7274	-3.00	I(1)
lnOil	-2.0819	-2.93	-3.7868	-3.00	I(1)
lnTransfers	-0.5801	-2.93	-3.1544	-3.00	I(1)

Note: compiled by the authors

The ADF test results show that inflation is stationary at level, I(0), whereas Rate, FX, lnOil, and lnTransfers become stationary after first differencing and are therefore integrated of order one, I(1). None of the variables is integrated of order two, which supports the application of the ARDL approach.

Since the ADF test confirmed that the variables are integrated of order I(0) and I(1), with none integrated of order I(2), the ARDL approach was applied. Given the relatively small annual sample, the maximum lag length was restricted

to one to preserve degrees of freedom and avoid overparameterization. Within this restriction, the lag structure was selected using the Akaike Information Criterion (AIC), resulting in an ARDL (1,1,1,1,1) specification.

Following the lag selection and bounds testing procedure, the ARDL (1,1,1,1,1) model was estimated to examine the dynamic relationship between inflation and the selected macroeconomic factors. The estimated coefficients are presented in Table 5.

Table 5. Results of ARDL estimation for 2000-2025

Variable	Estimate	Std. Error	t-value	p-value
Constant	-11.1068	6.6476	-1.671	0.1155
Inflation (-1)	0.5461	0.4158	1.313	0.2088
Rate	0.2245	0.2559	0.877	0.3942
Rate (-1)	-0.1242	0.4934	-0.252	0.8047
FX	0.0433	0.0273	1.588	0.1332
FX (-1)	-0.0733	0.0300	-2.443	0.0274**
lnOil	6.9936	2.1124	3.311	0.0048***
lnOil (-1)	-3.8113	1.9353	-1.969	0.0677*
lnTransfers	5.8977	4.0665	1.450	0.1676
lnTransfers (-1)	1.5340	3.1416	0.488	0.6324

*Coefficients are statistically significant at ***1%, **5%, *10% level of significance.*

Note: compiled by the authors

The estimation results show that the ARDL model is statistically significant overall ($F = 3.159$, $p = 0.0239$) and explains approximately 65.5% of the variation in inflation ($R^2 = 0.6546$). At the 5%

significance level, the lagged exchange rate and the current oil price are statistically significant. The coefficient of the lagged exchange rate is negative ($\beta = -0.0733$, $p = 0.0274$), indicating a significant

lagged relationship between exchange rate movements and inflation. The current coefficient of $\ln Oil$ is positive and statistically significant ($\beta = 6.9936$, $p = 0.0048$), indicating a significant relationship between global oil prices and inflation in Kazakhstan. The lagged oil price is significant only at the 10% level ($p = 0.0677$). In contrast, the current and lagged coefficients of the monetary policy interest rate are statistically insignificant at the 5% level. The coefficients of National Fund

transfers and their first lag are also statistically insignificant. Overall, the results indicate that exchange rate movements and global oil prices have the most pronounced statistical relationships with inflation within the estimated ARDL specification.

The ARDL bounds test was applied to examine whether a long-run relationship exists between inflation and the explanatory variables. Table 6 reports an F-statistic of 2.4282 and a p-value of 0.3762.

Table 6. Results of cointegration test

Model	Test statistic	p-value	Decision
ARDL (1,1,1,1,1)	2.4282	0.3762	No evidence of cointegration

Note: compiled by the authors

The null hypothesis of no level relationship cannot be rejected. The bounds-test results therefore do not provide evidence of a long-run relationship between inflation and the explanatory variables over the study period.

The estimation results were also used to evaluate the research hypotheses formulated in the literature review. H1, which assumed a significant relationship between the monetary policy interest rate and inflation, was not supported, as both the current and lagged coefficients of the interest rate were statistically insignificant. H2 was supported, as the lagged exchange rate coefficient was

statistically significant at the 5% level ($p = 0.0274$). H3 was also supported, with the current oil price coefficient being statistically significant at the 1% level ($p = 0.0048$). H4 was not supported, as the current and lagged coefficients of National Fund transfers were statistically insignificant. However, joint tests of the current and lagged coefficients are needed to assess the overall significance of each explanatory variable.

To assess the adequacy of the estimated ARDL model, several diagnostic tests were performed. The results are presented in Table 7.

Table 7. Diagnostic tests for the ARDL Model

Diagnostic	Test statistic	P-value	Result
Serial correlation	0.0203	0.8886	No evidence of first-order serial correlation
Heteroskedasticity	14.386	0.1092	No evidence of heteroskedasticity
Jarque-Bera	0.1091	0.9469	Normality not rejected

Note: compiled by the authors

The diagnostic tests indicate that the estimated model satisfies the main residual assumptions. The Breusch-Godfrey LM test shows no evidence of first-order serial correlation ($p = 0.8886$), while the Breusch-Pagan test indicates no evidence of heteroskedasticity ($p = 0.1092$). In addition, the Jarque-Bera test does not reject the null hypothesis of residual normality ($p = 0.9469$).

The stability of the estimated ARDL model was examined using the Recursive CUSUM and OLS-based CUSUM tests. These tests are used to identify possible parameter instability over the estimation period. The results are presented in Figure 3.

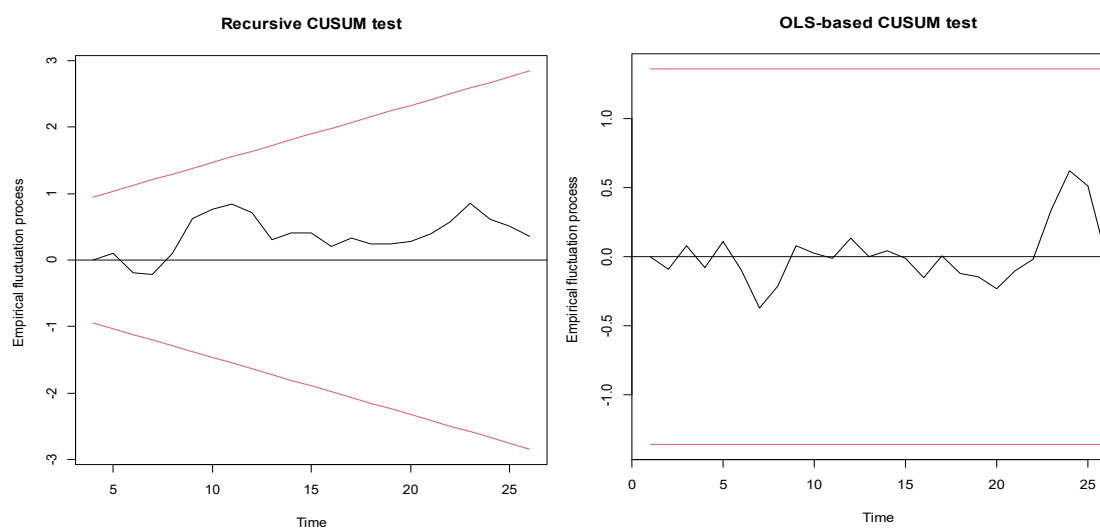


Figure 3. Recursive CUSUM and OLS-based CUSUM stability tests

As shown in Figure 3, the Recursive CUSUM statistic remains within the 5% critical bounds throughout the estimation period. Similarly, the OLS-based CUSUM statistic does not cross the corresponding critical boundaries. Thus, both tests provide no evidence of parameter instability and indicate that the estimated ARDL specification remains stable over the study period.

A noticeable upward shift around 2014–2015 suggests a change in volatility dynamics, however, this change does not exceed the critical bounds and therefore does not violate variance stability. The 2014–2015 shift corresponds to the oil price shock and exchange rate regime change in Kazakhstan, which increased short-term volatility without causing structural instability. Thus, the model demonstrates acceptable stability properties, supporting the reliability of the estimated long-run and short-run coefficients.

CONCLUSION

This study examined the relationships between inflation and selected macroeconomic factors in Kazakhstan using annual data for 2000–2025 and an ARDL model. The analysis included the monetary policy interest rate, the KZT/USD exchange rate, global oil prices, and National Fund transfers.

The empirical results show that the lagged exchange rate and current global oil prices are statistically significant in the estimated model. The lagged exchange rate has a negative coefficient (β

$= -0.0733$, $p = 0.0274$), indicating an inverse lagged relationship with inflation within the estimated specification. This finding should be interpreted cautiously and does not imply a general negative effect of exchange rate depreciation on inflation. In contrast, the coefficient on current $\ln\text{Oil}$ is positive and statistically significant ($\beta = 6.9936$, $p = 0.0048$), indicating a positive association between oil prices and inflation within the estimated model.

The current and lagged coefficients of the policy interest rate and $\ln\text{Transfers}$ are individually insignificant at the 5% level. These results should not be interpreted as evidence that monetary policy and National Fund transfers have no relationship with inflation. Joint coefficient tests and further analysis of indirect transmission channels are needed to assess their roles more fully.

The ARDL bounds test does not provide evidence of a long-run cointegrating relationship among the variables ($F = 2.4282$, $p = 0.3762$). Therefore, the estimated coefficients are interpreted as dynamic relationships within the ARDL specification rather than as long-run equilibrium effects. The diagnostic and stability tests indicate that the estimated model satisfies the main residual assumptions and provides no evidence of parameter instability.

The findings suggest that external macroeconomic conditions, particularly exchange rate dynamics and global oil prices, should be considered when assessing inflation developments in Kazakhstan. At the same time, the insignificant coefficients of the policy interest rate and National Fund transfers

indicate the need for further investigation of their transmission mechanisms rather than conclusions about their ineffectiveness. Based on the empirical results, several policy implications can be identified. Given the statistically significant association between inflation and the lagged exchange rate, greater attention should be paid to exchange rate developments when assessing inflationary risks. The significant positive relationship between global oil prices and inflation also supports the inclusion of external commodity price developments in inflation monitoring and forecasting. At the same time, the statistically insignificant coefficients of the monetary policy interest rate and National Fund transfers should not be interpreted as evidence of policy ineffectiveness; rather, they indicate the need for further analysis of their transmission mechanisms. Therefore, monetary and fiscal policy decisions should be supported by continued assessment of how external shocks and domestic policy variables are transmitted to inflation.

Future research could examine these mechanisms using higher-frequency data and models that explicitly identify the transmission channels between oil prices, fiscal policy, exchange rate movements, monetary policy, and inflation. The findings are subject to the small annual sample, the limited lag structure, and the exclusion of other potential inflation drivers. Future research could use higher-frequency data, assess sensitivity to alternative specifications, and examine the transmission channels linking oil prices, fiscal policy, exchange rates, monetary policy, and inflation.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: ZY; research design: ZY; data collection: ZY, NA and AZ; analysis and interpretation: ZY, NA and AZ; writing draft preparation: ZY; supervision: ZY, NA and AZ; correction of article: ZY, NA and AZ; proofread and final approval of article: ZY, NA and AZ. All authors have read and agreed to the published version of the manuscript.

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Corporate Security and Financial Stability of Ukrainian Banks under Crisis Conditions

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ABSTRACT

In the context of growing challenges to the security of the banking sector during Ukraine's post-war economic transformation, it has become necessary to rethink approaches to the strategic management of banks with an emphasis on security factors. This study addresses the insufficient integration of corporate security factors into comprehensive models for assessing and managing the financial stability of commercial banks under wartime conditions. The methodological framework combined structural and functional analysis, scenario forecasting, and econometric modeling. The initial information base consisted of data from the National Bank of Ukraine, financial and non-financial statements of 10 banks, materials from international rating agencies, and publicly available corporate data. The results revealed significant heterogeneity in the financial parameters of the banks under study. The highest capital adequacy ratios were recorded at Credit Agricole Bank – 24.5% and Raiffeisen Bank – 23.8%, while Ukreximbank's figure was 16.1%. The share of non-performing loans reached 28.9% at Ukreximbank and 23.7% at Oschadbank. Universal Bank reported the highest return on assets – 1.1%, and the level of credit risk coverage by reserves at PrivatBank and Credit Agricole Bank was 98% each. Standardized sensitivity coefficients between the corporate security index and ROA increase from 0.47 to 0.78, and with CAR — from 0.33 to 0.66, while an inverse relationship remains for NPL, ranging from –0.52 to –0.70. The results obtained can be used by regulatory bodies, the management of banking institutions, and analytical organizations when developing policies to ensure financial security in the context of the structural transformation of the economy.

KEYWORDS: Financial Economy, Financial Stability, Bank, Banking Sector, Banking Stability, Cybersecurity, Ukraine

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Корпоративная безопасность и финансовая устойчивость банков Украины в условиях кризиса

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АННОТАЦИЯ

В условиях растущих вызовов безопасности банковского сектора в период послевоенной экономической трансформации Украины возникла необходимость переосмысления подходов к стратегическому управлению банками с уделением особого внимания факторам безопасности. В данном исследовании рассматривается проблема недостаточной интеграции факторов корпоративной безопасности в комплексные модели оценки и управления финансовой стабильностью коммерческих банков в условиях военного времени. Методологическая основа сочетала структурный и функциональный анализ, сценарное прогнозирование и эконометрическое моделирование. Исходную информационную базу составили данные Национального банка Украины, финансовая и нефинансовая отчетность 10 банков, материалы международных рейтинговых агентств и открытые корпоративные данные. Результаты показали существенную неоднородность финансовых параметров исследуемых банков. Наиболее высокие значения достаточности капитала зафиксированы у Credit Agricole Bank – 24.5% и Raiffeisen Bank – 23.8%, тогда как у Ukreximbank показатель составил 16.1%. Доля неработающих кредитов достигала 28.9% в Ukreximbank и 23.7% в Oschadbank. Наибольшая рентабельность активов отмечена у Universal Bank – 3.1%, а уровень покрытия кредитных рисков резервами у PrivatBank и Credit Agricole Bank составил по 98%. Стандартизированные коэффициенты чувствительности между индексом корпоративной безопасности и ROA увеличиваются от 0,47 до 0,78, с CAR – от 0,33 до 0,66, тогда как для NPL сохраняется обратная связь от –0,52 до –0,70. Полученные результаты могут быть использованы регулирующими органами, руководством банковских учреждений и аналитическими организациями при разработке политики обеспечения финансовой безопасности в контексте структурной трансформации экономики.

КЛЮЧЕВЫЕ СЛОВА: финансовая экономика, финансовая устойчивость, банк, банковский сектор, банковская стабильность, кибербезопасность, Украина

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INTRODUCTION

The stability of the banking sector has become a critical component of Ukraine's financial and economic security amid prolonged military uncertainty, structural disruptions, and rising systemic risks. The full-scale invasion has significantly changed the operating environment for Ukrainian banks, increasing the importance of adaptive management approaches to maintain solvency, operational continuity, and institutional resilience. Previous studies show that financial technologies, risk management mechanisms, and institutional adaptation help strengthen financial system stability under uncertainty (Sirenko et al., 2020; Poltorak et al., 2021). Recent research has also emphasised the importance of monitoring systems, digital transformation and external support mechanisms in maintaining financial stability during periods of crisis (Atamanyuk et al., 2024; Buriachenko et al., 2025).

Traditional approaches to banking management have mainly focused on individual financial indicators, including capital adequacy, liquidity, credit risks and profitability. However, the contemporary risk environment demonstrates that banking resilience depends not only on financial performance but also on a wider set of factors, including cybersecurity, information reliability, personnel stability, legal protection and reputational sustainability. Therefore, corporate security should be treated as an integrated management dimension that influences banks' ability to withstand systemic shocks and adapt to structural transformations.

This study addresses the insufficient integration of corporate security factors into comprehensive models for assessing and managing the financial stability of commercial banks under wartime conditions. Existing approaches often analyse separate risk categories or financial indicators without considering the interrelationship between different security components and their combined influence on banking resilience.

This study aims to assess the relationship between corporate security and the financial stability of Ukrainian banks and to develop a security-oriented management framework based on empirical assessment and post-war recovery scenarios. The study addresses the following research questions:

RQ1. What differences exist in the level of

corporate security among Ukrainian commercial banks under wartime conditions?

RQ2. How is corporate security associated with key indicators of Ukrainian banks' financial stability?

RQ3. How can security-oriented management contribute to strengthening banking resilience under alternative post-war recovery scenarios?

The scientific novelty of the study lies in the development of an integrated framework for assessing corporate security as a multidimensional component of banking stability. Unlike approaches focused primarily on financial indicators, the proposed framework integrates financial, economic, informational, technological, personnel, legal, physical, and reputational dimensions and combines multidimensional assessment with scenario modelling to examine potential recovery trajectories of the Ukrainian banking sector. The practical contribution of the study lies in providing a structured analytical basis for identifying security vulnerabilities across banking institutions and supporting adaptive management decisions under conditions of macro-financial uncertainty.

LITERATURE REVIEW

Previous studies have examined banking stability from different perspectives, including financial security assessment, risk management, digital transformation and institutional resilience. Sirenko et al. (2020) showed that the development of financial technologies strengthens financial security by reducing shadow transactions and improving control over payment infrastructure. Poltorak et al. (2021) developed approaches for modelling financial security levels using multifactor systems of macroeconomic indicators, allowing the identification of stabilisation parameters within financial systems.

Recent research has expanded the understanding of banking resilience by incorporating monitoring mechanisms, technological development and organisational adaptation. Atamanyuk et al. (2024) proposed analytical monitoring approaches to identify systemic risks more quickly. Buriachenko et al. (2025) examined the influence of external economic, military and diplomatic factors on financial stability through exchange reserves, debt structures and financial markets.

Other studies have highlighted the importance of internal management mechanisms. Makarychev and Sazonov (2025) showed that weaknesses in institutional banking supervision may lead to reputational losses and reduced trust in financial institutions. Abidovna (2023) emphasised the importance of strengthening risk management units, integrating information technologies and improving human resource management practices. Siddique et al. (2022) demonstrated that loan portfolio quality and risk management approaches remain important determinants of banking performance.

Research conducted in different national contexts also highlights the importance of organisational flexibility, operational risk management and digital transformation. Al Zaidanin and Al Zaidanin (2021) examined the role of credit risk management in bank performance, while Hac et al. (2021) focused on risk management culture under changing macroeconomic conditions. Al-kiyumi et al. (2021) considered

operational risk management, and Qasim and Anwar (2022) analysed credit risk management practices in commercial banks. More recently, Xie and Wang (2023) showed how digital transformation can affect the development and performance of commercial banks. Taken together, these studies indicate that banking resilience depends on both financial risk management and broader organisational and technological adaptation.

Against this background, security-oriented management can be considered a broader approach to banking resilience than traditional risk management. While traditional risk management primarily focuses on financial, credit, market and operational risks, security-oriented management also incorporates organisational, informational, technological, personnel, legal, reputational and physical dimensions. The main differences between these approaches are summarised in Table 1.

Table 1. Comparative characteristics of traditional risk management and security-oriented bank management

Criterion	Traditional risk management	Security-oriented bank management
Goal orientation	Minimisation of financial losses, compliance with regulations	Ensuring corporate resilience, protection against multi-vector threats, strategic stability
Objects of influence	Credit, market, operational and liquidity risks	All components of corporate security: financial, information, legal, personnel, technological, reputational
Time horizon	Short- and medium-term control of risk events	Long-term scenario planning and forecasting the impact of systemic threats
Management tools	Risk analysis, reserving, limiting, stress testing	Comprehensive compliance system, security audit, response protocols, cyber defense, adaptive strategies
Adaptability	Limited, mostly reactive	High, with elements of proactive management, dynamic updating of procedures

Note: compiled by the authors

Comparative analysis confirms that security-oriented management provides an expanded platform for banks' strategic responsibility under conditions of systemic instability and high uncertainty. Unlike traditional risk management, which is predominantly reactive and event-driven, a security-oriented approach encompasses a broader set of target parameters and integrates managerial, technological, and regulatory protection tools into a unified management architecture. It places particular emphasis on proactive monitoring, scenario forecasting, and preventive measures,

which together form the foundation for long-term institutional stability in the context of post-war economic recovery.

Based on the reviewed literature and international regulatory approaches, corporate security in banking can be structured into eight interrelated components: financial, economic, information, physical, personnel, technological, reputational and legal security. These components and the indicators commonly used for their assessment are presented in Table 2.

Table 2. Matrix of components of corporate security of a banking institution and typical assessment indicators

Corporate security component	Typical indicators for evaluation
Financial security	Capital Adequacy Ratio (CAR), NPL ratio, liquidity, cost-to-income ratio, ROA, provisioning level
Information security	Number of cyber incidents, availability of a certified ISMS (ISO/IEC 27001), IT security costs, RTO, share of cybersecurity in the IT budget
Personnel security	Staff turnover, critical access share, integrity checks, labor violations
Technological security	Redundant data center, failure rate, digital readiness level, process automation
Legal security	Number of litigations, inspections with violations, regulatory compliance, legal risks
Reputational security	Trust index, negative mentions, customer satisfaction (CSAT), ratings (Moody's, S&P), scandals
Physical security	Physical intrusion incidents, security systems, evacuation training, access control
Economic security	Market share dynamics, currency dependence, client concentration, government regulation
<i>CAR – Capital Adequacy Ratio; ROA – Return on Assets; NPL – Non-Performing Loans; ISMS – Information Security Management System; RTO – Recovery Time Objective; CSAT – Customer Satisfaction Score</i>	

Note: authors' calculations based on National Bank of Ukraine (2025), Moody's Investors Service (2025), ISO/IEC (2022)

The components are closely interconnected. Weaknesses in information security may affect reputation, while personnel-related problems may increase legal and operational risks. A multidimensional assessment therefore provides a broader view of banking resilience than the analysis of individual financial indicators alone.

Despite the significant contribution of previous studies, several limitations remain. Existing research predominantly focuses either on financial indicators or on specific risk categories, such as credit risk, operational risk or cybersecurity. The institutional dimension of corporate security, including the combined influence of organisational, technological, informational and reputational factors on financial stability, remains insufficiently explored.

Therefore, this study addresses the research gap of a comprehensive model that integrates corporate security assessment with financial stability analysis and scenario-based forecasting for banks operating under wartime uncertainty. This study aims to address this gap by developing a multidimensional corporate security assessment framework and analysing its implications for the future resilience and recovery of the Ukrainian banking sector.

Despite the growing body of research on banking stability, most studies focus on individual financial indicators or specific types of risk, including credit, operational and cybersecurity risks. The broader concept of corporate security, which also includes organisational, technological, informational, personnel, legal, physical and reputational

dimensions, has received less attention. There is also limited research combining such a multidimensional assessment with scenario analysis, particularly in the context of wartime uncertainty. This study addresses this gap by combining corporate security assessment with financial stability analysis and scenario analysis. The proposed framework is applied to Ukrainian banks to examine their resilience under wartime conditions and possible post-war recovery scenarios.

MATERIALS AND METHODS

The study employed an applied analytical and modelling approach to assess corporate security and financial stability in Ukrainian banks. The empirical assessment focused on 2024 as the reference year, while data for 2020–2023 were used, where relevant, to provide background information on changes in selected financial indicators and the broader transformation of the Ukrainian banking sector.

Primary statistical information was collected from the National Bank of Ukraine (2025) materials, specifically the Financial Stability section for 2020–2024. The analysis focused on ten banking institutions that, as of the end of 2024, held the largest market share in terms of assets, thereby ensuring representativeness of the sample and coverage of the key strategic players in the financial system. These included: Credit Agricole Bank (2025), Raiffeisen Bank International (2024), Universal Bank (2025), First Ukrainian International Bank

(2025), PrivatBank (2025), Ukrgasbank (2025), Oschadbank (2025), Ukreximbank (2025), A-Bank (2025) and OTP Bank (2025). The sample was selected based on the ranking of Ukrainian banks by total assets as of the end of 2024, according to National Bank of Ukraine statistics. The study included the ten largest banking institutions by asset volume, which collectively represented the major share of the Ukrainian banking sector and reflected different ownership models, including state-owned, foreign and private banks. The selection criterion was each bank's position in the asset ranking, while systemic importance, market coverage, and strategic role in the financial system were considered additional factors confirming the sample's representativeness. The analysis employed a stratification of banks by organisational type into three groups – state-owned, foreign and private – which enabled consideration of differences in strategic approaches to risk management depending on institutional status. Additionally, rating reports from international agencies, including S&P Global Ratings (Fojcik, 2024), Fitch Ratings (2024), and Moody's Investors Service (2025), were used to provide a comparative basis for assessing banking reliability under conditions of high macro-financial volatility.

The institutional basis of the security-oriented management framework drew on recommendations of the Basel Committee on Banking Supervision and the Bank for International Settlements (2022). International information-security standards were also considered, including ISO/IEC (2022) Information Security Management Systems – Requirements and NIST SP 800-53 issued by the National Institute of Standards and Technology (2020). These sources provided a regulatory and methodological basis for identifying the main dimensions of corporate security relevant to banks operating under wartime conditions and prospective post-war recovery.

Corporate security was assessed using a structural-functional approach. Eight components were distinguished: financial, economic, informational, physical, personnel, technological, reputational and legal security. Each component included a set of indicators derived from bank reporting, National Bank of Ukraine statistics and publicly available analytical sources.

The financial component included the capital

adequacy ratio (CAR), non-performing loan ratio (NPL), return on assets (ROA) and provisioning coverage ratio. Economic security was assessed using indicators related to market position, client concentration and currency dependence. Information security covered information-security management, cybersecurity and operational reliability. The technological component reflected digital infrastructure, process automation and continuity of IT services. Personnel security included staff stability, personnel turnover and organisational resilience. Legal and reputational security covered regulatory compliance, legal risks, customer trust and reputation-related indicators. Physical security reflected the protection of critical infrastructure and operational continuity.

The indicators were normalised to the interval [0,1] using the min-max transformation. For stimulants, where higher values indicated stronger corporate security, the following formula was applied: $Z_{ij} = (X_{ij} - X_{min}) / (X_{max} - X_{min})$. For destimulants, where higher values indicated increased risk, the reverse transformation was used: $Z_{ij} = (X_{max} - X_{ij}) / (X_{max} - X_{min})$. Equal weights were assigned to all indicators within each component, and each of the eight components contributed equally to the final corporate security index. The integral corporate security index was calculated as the arithmetic mean of the eight component values.

An integral assessment was obtained by calculating the average value of normalised indicators within each block and aggregating the eight component scores with equal weights, which ensured comparability across banks and conceptualised corporate security as a multidimensional category. The average value was calculated according to the formula (1):

$$I_j = \frac{1}{n} \sum_{i=1}^n Z_{ij} \quad (1)$$

where:

I_j – the integral indicator of block;

Z_{ij} – the normalised value of indicator;

n – the number of indicators in the respective block.

Banks were classified according to the value of the integral index. Values of 0.75 and above were interpreted as a high level of corporate security, values from 0.60 to below 0.75 as a medium level,

and values below 0.60 as a low level. The same thresholds were applied consistently across the analysed institutions.

Scenario analysis was used to examine banking stability under three alternative macro-financial conditions: protracted crisis, partial stabilisation and active recovery. The scenarios were characterised using five financial and risk parameters: NPL ratio, ROA, CAR, currency volatility and bank capitalisation. The scenario values were used as analytical assumptions for comparing possible changes in banking stability under different external conditions rather than as point forecasts of future outcomes.

To examine the relationship between corporate security and selected financial stability indicators, exploratory econometric analysis was conducted using simple ordinary least squares regression. Separate models were estimated for ROA, CAR, NPL, liquidity coverage and capitalization (2):

$$Y_i = \beta_0 + \beta_1 \times CS_i + \varepsilon_i \quad (2)$$

where:

Y_i – the selected financial stability indicator for bank;

CS_i – the integral corporate security index;

β_0 – the intercept;

β_1 – the estimated sensitivity coefficient, and ε_i is the error term;

ε_i – the error term.

Because several financial indicators used as dependent variables are also included in the financial component of the integral corporate security index, the regression coefficients were interpreted as exploratory sensitivity measures rather than independent causal effects. The purpose of the analysis was therefore to assess the direction and relative strength of associations between the overall security profile and selected financial stability parameters. The models were estimated using MS Excel and Python with the statsmodels package. Statistical significance was assessed at the 5% significance level ($p < 0.05$). The results of the integral assessment and scenario analysis were subsequently used to identify differences in banks' security profiles and their sensitivity to alternative macro-financial conditions and to formulate a security-oriented management framework for wartime conditions and prospective post-war recovery.

RESULTS

The assessment of corporate security among Ukrainian commercial banks begins with a comparison of their main institutional and market characteristics. These characteristics provide the context for interpreting differences in corporate security across the selected institutions. Table 3 summarises the banks by ownership type, asset market share in 2024, regional presence and systemic importance.

Table 3. List of banks studied and their basic characteristics (2024)

Bank name	Property type	Asset market share, %	Regional presence	Systemic significance
JSC CB "PrivatBank"	State	20.1	All regions, the most extensive network	High
JSC "Oschadbank"	State	14	All regions, specialisation in state programs	High
JSC "Ukreximbank"	State	9.8	Central office, corporate network	High
JSC "UkrGasbank"	State	5.7	100+ branches, green financing	Medium
JSC "Raiffeisen Bank"	Foreign	6.1	Present in 23 regions, digital channels	High
JSC "PUMB"	Private	4.2	Industrial regions, corporate segment	High
JSC "Universal Bank"	Private	4	Online model (Monobank), no branches	Medium
JSC "A-Bank"	Private	2.9	180+ branches, available in all regions	Medium
JSC "Credit Agricole Bank"	Foreign	2.5	Big cities, focus on the agricultural sector	Medium
JSC "OTP Bank"	Foreign	2.4	Emphasis on corporate lending	Medium

Note: authors' calculations based on the National Bank of Ukraine (2025), Credit Agricole Bank (2025), Raiffeisen Bank International (2024), Universal Bank (2025), First Ukrainian International Bank (2025), PrivatBank (2025), Ukrgasbank (2025), Oschadbank (2025), Ukreximbank (2025), A-Bank (2025), OTP Bank (2025), Fojeik (2024), Fitch Ratings (2024), Moody's Investors Service (2025)

The data presented in Table 3 show considerable structural differences among the selected banks in terms of ownership, asset market share and systemic importance. Four state-owned banks – PrivatBank (20.1%), Oschadbank (14.0%), Ukreximbank (9.8%) and Ukrgasbank (5.7%) – together account for 49.6% of the reported asset market share. This concentration highlights the important role of state-owned institutions in the Ukrainian banking system.

Foreign-owned banks, including Raiffeisen Bank (6.1%), Credit Agricole Bank (2.5%) and OTP Bank (2.4%), have smaller individual market shares but operate within international corporate governance and risk-management frameworks. Private banks, particularly PUMB (4.2%) and Universal Bank (4.0%), are characterised by business models with a strong focus on retail and digital services. These

differences in ownership structure, market position and operating models provide an important context for the subsequent assessment of corporate security.

Differences in ownership, market scale, regional presence and operating models may be associated with different approaches to risk management and corporate security. These institutional characteristics are therefore considered when interpreting the financial and multidimensional security profiles of the analysed banks. The values of the selected financial indicators in 2024 show considerable variation across the analysed banks. Figure 1 presents capital adequacy, non-performing loans, return on assets and provisioning coverage, providing a basis for the comparative assessment of the financial component of corporate security.

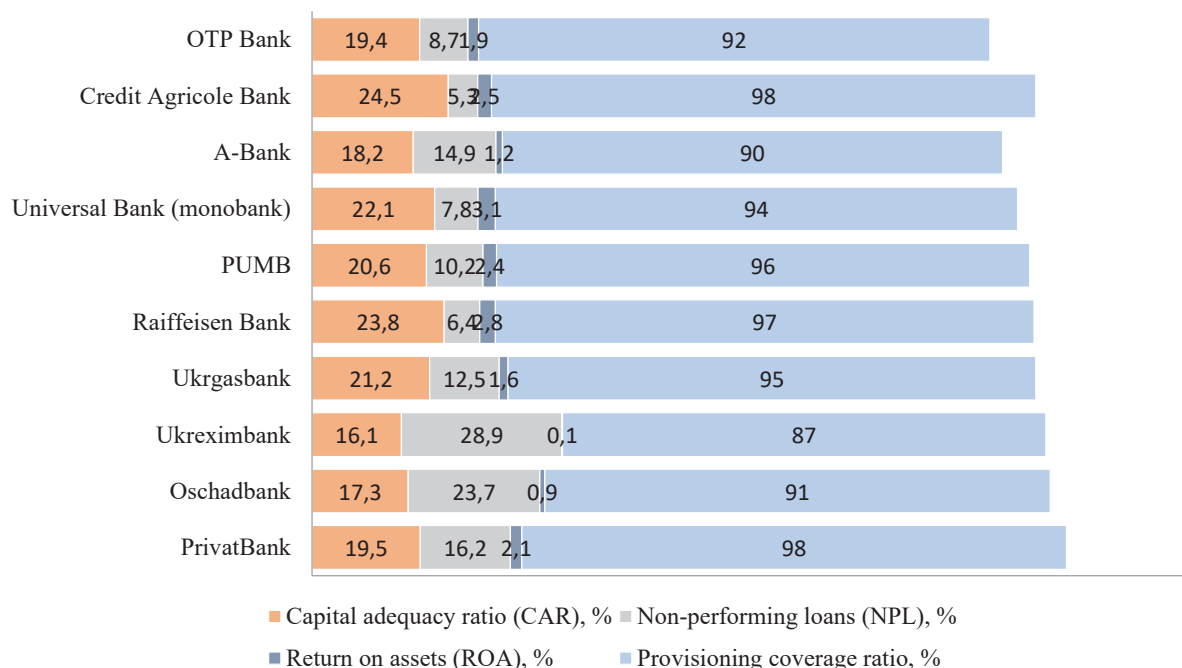


Figure 1. Selected financial indicators of Ukrainian banks, 2020-2024

The comparative analysis presented in Figure 1 shows considerable differences among Ukrainian banks in key financial security indicators. Credit Agricole Bank (24.5%) and Raiffeisen Bank (23.8%) recorded the highest capital adequacy ratios, indicating relatively strong capital buffers. By contrast, Ukreximbank showed the lowest value (16.1%), suggesting a lower capacity to absorb potential losses compared with the other banks in the sample. The share of non-performing

loans exceeded 20% in Ukreximbank (28.9%) and Oschadbank (23.7%), indicating elevated credit risk. These institutions also recorded low or near-zero ROA values, which may limit their capacity to generate internal sources of capitalisation.

Universal Bank recorded the highest ROA (3.1%), indicating comparatively strong profitability. Loan loss provisioning was highest in PrivatBank and Credit Agricole Bank (98% each), suggesting a high level of coverage of identified credit risks. Overall,

the results show that the financial security profiles of the analysed banks differ substantially in terms of capital adequacy, asset quality, profitability and provisioning. However, financial indicators alone do not fully capture the multidimensional nature of

corporate security. Figure 2 therefore extends the analysis by presenting the component structure of the integral corporate security index and identifying differences in banks' overall security profiles.

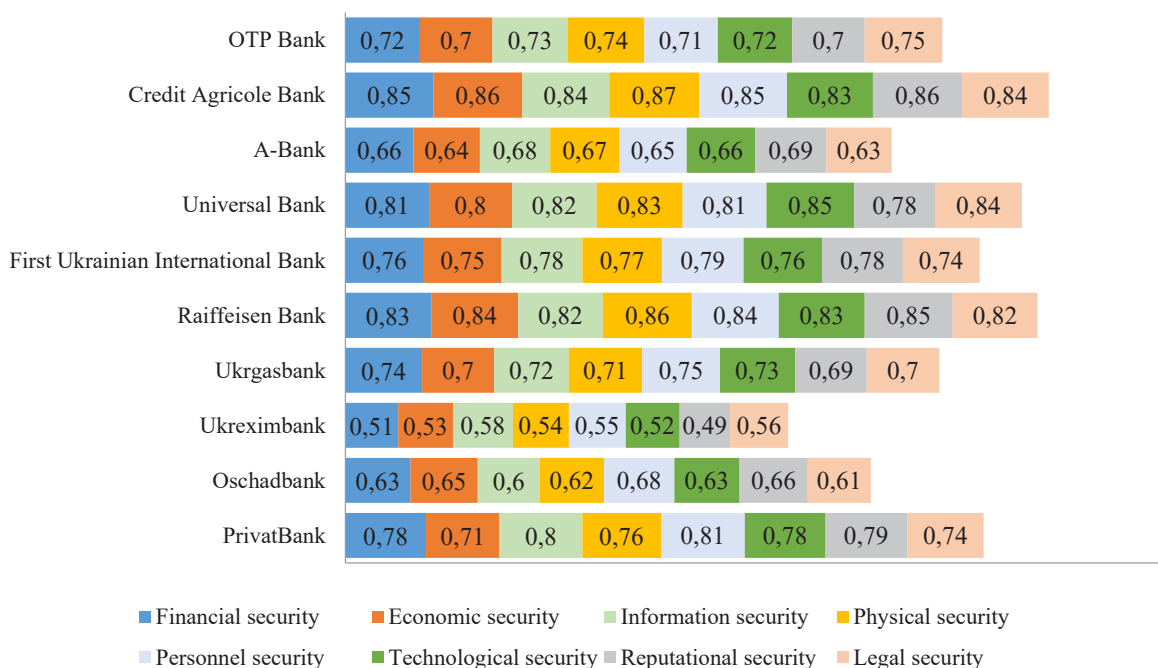


Figure 2. Integral assessment of the level of corporate security of Ukrainian banks by components, 2024

The final ranking of banks by integrated assessment of corporate security reveals a clear hierarchy of institutions by security level. The high-security group comprises Credit Agricole Bank (0.84), Raiffeisen Bank (0.85), Universal Bank (0.77), FUIB (0.75) and PrivatBank (0.76), all of which demonstrate a balanced profile across information, technological, financial and legal dimensions (with all indicators exceeding 0.70). The medium-security group includes Oschadbank (0.63), Ukrgasbank (0.71), A-Bank (0.64), and OTP Bank (0.70), where notable asymmetries are observed, particularly in the technological and economic components. Ukreximbank, with an integral score of 0.53, stands out as the only institution in the conditionally low-security category, mainly because of weak results in most components, especially reputation (0.49) and technology (0.52). These findings highlight both the strengths and vulnerabilities of individual banks' security systems.

The multidimensional assessment shows that corporate security cannot be explained by asset size or systemic importance alone. Differences are also associated with the balance of financial and non-financial security components, including information, technological, reputational and organisational dimensions. The results provide a basis for the subsequent scenario analysis and for identifying areas where individual banks may require greater managerial attention.

Based on the preceding assessment and the practices identified in regulatory, analytical and bank reporting sources, adaptive management measures were grouped into five functional areas. This classification links specific management practices with their expected contribution to banking resilience under conditions of heightened uncertainty. Table 4 summarises the proposed typology of adaptive management practices and their expected effects.

Table 4. Typology of adaptive management practices of banks by functional areas

Functional direction	Typical adaptive practices	Expected effect
Finances	Credit policy revision; accelerated provisioning; introduction of liquidity stress testing	Reducing credit risk; maintaining solvency; improving supervisory performance.
Human resources policy	Development of personnel reserve; remote personnel management; rotation and multifunctionality models	Stability of operational processes; reduction of losses due to staff turnover; increased management flexibility
Information technology	Transition to cloud infrastructure; implementation of zero trust architecture; institutionalization of SOC/CSIRT	Strengthening cyber resilience; protecting data and transactions; responding quickly to IT incidents
Legal environment	Centralisation of compliance procedures; integration of legal monitoring into operational activities	Reducing sanctions and reputational risks; increasing regulatory compliance.
Communications	Implementation of reputation intelligence tools; online monitoring of client signals; social risk management	Strengthening customer trust; timely response to image threats; increasing social capital

Note: authors' calculations based on the National Bank of Ukraine (2025), Credit Agricole Bank (2025), Raiffeisen Bank International (2024), Universal Bank (2025), First Ukrainian International Bank (2025), PrivatBank (2025), Ukrgasbank (2025), Oschadbank (2025), Ukreximbank (2025), A-Bank (2025), OTP Bank (2025), Fojcik (2024), Fitch Ratings (2024), Moody's Investors Service (2025)

The typology of adaptive management practices reflects banks' aspiration for a multi-vector transformation of their organizational models in a risk-prone environment. In the financial sphere, key measures include strengthening reserves and implementing liquidity stress testing, which respond to anti-crisis management requirements. The personnel dimension focuses on operational stability through the formation of multifunctional staff and the use of rotational mechanisms. Within the IT sector, approaches aimed at enhancing cyber resilience prevail, particularly through the adoption of zero-trust architecture and the activation of interaction with CSIRT units. The legal and communication blocks illustrate a shift towards integrated risk control, combining regulatory compliance with reputational transparency.

This framework forms the basis for the further development of a holistic model of security-oriented management, adapted to the post-war restoration of the financial system. The conceptual model of security-oriented management in banking institutions requires a clear definition of its structural components and the functional content of each block. To ensure the integrity of the management architecture, the model incorporates six key areas: risk management, cybersecurity, personnel, legal, reputational, and technological security. Each component operates autonomously yet remains interconnected in contributing to the bank's overall financial and economic stability. Table 5 presents a substantive description of these blocks, specifying their role in adaptive anti-crisis management.

Table 5. Components of the conceptual model of security-oriented management and their functional content

Model component	Functional purpose
Risk management	Identification, monitoring, and scenario forecasting of financial, operational, market, and geopolitical risks; construction of dynamic early warning indicator systems
Cybersecurity	Digital perimeter protection, anomalous activity monitoring, zero trust architecture implementation, and SOC/CSIRT institutionalization for rapid response
Personnel security	Formation of an adaptive personnel reserve, support for team stability, organization of internal training, ensuring management continuity in crises
Legal support	Ensuring legal compliance, prevention of sanctions and contractual risks, compliance monitoring, legal support for information protection

Reputational security	Monitoring social and public risks, image management in the digital environment, forecasting narrative threats, supporting the stability of trust.
Technological sustainability	IT infrastructure redundancy, scalability of digital services, ensuring functional continuity, implementation of adaptive architectures based on cloud technologies

Note: authors' calculations based on the Bank for International Settlements (2022), ISO/IEC (2022), National Institute of Standards and Technology (2020)

The proposed structural model offers a holistic perspective of the security management system as an interconnected complex of functional blocks. Particularly significant is the interaction between risk management and the technological and reputational subsystems, which enables the effective localisation of threats of both internal and external origin. Cybersecurity and legal support act as institutional filters, preventing critical incidents from escalating, while the human resource component underpins adaptability and continuity in management processes. The complexity of implementing each block is amplified by the integration of digital technologies, which, in the context of hybrid challenges, becomes a key determinant of banking stability. Accordingly, the model may serve as an analytical foundation for further deploying management transformation strategies aimed at strengthening systemic security.

It should be emphasised that modelling security-oriented management of commercial banks in the context of post-crisis recovery requires a multi-component approach, focused on the integration of functionally autonomous yet strategically interdependent management blocks. The proposed conceptual model encompasses six key areas – risk management, cybersecurity, human resources, legal, reputational, and technological security – which together form a holistic architecture for the stability

of the banking system. Its adaptive character is grounded in verified empirical data and established anti-crisis practices, ensuring high relevance to contemporary challenges in a hybrid environment. This structural configuration provides the basis for developing institutional mechanisms to enhance financial stability, a defining element of the state's broader system of financial and economic security.

To assess the economic potential of a security-oriented management model for banking institutions, modeling scenarios for the development of the macro-financial environment is particularly important. Given the complex security situation and the multi-vector nature of external risks, it is appropriate to distinguish three basic contexts of banking sector functioning: protracted crisis, partial stabilisation, and active economic recovery. Each scenario corresponds to a specific risk profile that determines banks' susceptibility to macroeconomic shocks and the variability of financial outcomes, depending on the depth of integration of security practices. A comparative analysis of these conditions makes it possible to identify the stabilising effect of corporate security measures and to assess the potential efficiency gains from their systemic implementation. Table 6 presents the key parameters used to characterise three alternative macro-financial scenarios.

Table 6. Key parameters of alternative macro-financial scenarios

Risk parameter	Scenario 1: Protracted crisis	Scenario 2: Partial stabilisation	Scenario 3: Active recovery
NPL, %	22.0-26.5	13.0-14.5	7.0-8.5
ROA, %	0.3-0.6	1.2-1.5	3.0-3.4
CAR, %	15.0-17.0	19.0-21.0	22.5-24.0
Currency volatility (UAH/USD)	High (>20% fluctuation)	Moderate (8-12%)	Low (<5%)
Annual bank capitalisation growth, %	Negative/close to zero	Stable growth (5-7%)	Accelerated growth (10-13%)

Note: authors' calculations based on the National Bank of Ukraine (2025), Fojcik (2024), Fitch Ratings (2024), Moody's Investors Service (2025)

The scenario approach provides a structured basis for examining how key financial stability indicators may vary under different macro-financial conditions. The three scenarios are differentiated by the expected levels of NPLs, ROA, CAR, currency volatility and bank capitalisation. These parameters allow the financial risk environment to be compared across conditions ranging from prolonged instability to active recovery.

In the protracted crisis scenario, systemic instability reaches critical levels. This is reflected in persistently high NPLs and a sharp decline in ROA to 0.3-0.6p.p., signaling minimal profitability of banking operations. CAR falls to 15.0-17.0 p.p., indicating capital erosion, while currency volatility exceeds 20 p.p., amplifying solvency risks. Capitalisation rates either stagnate or turn negative, which threatens investor withdrawals and necessitates regulatory intervention. Without integrated security mechanisms, these dynamics may have a cumulative destabilizing effect, exacerbating banks' vulnerability to multiple risk factors.

The partial stabilisation scenario reflects moderate improvements in financial security. NPLs decline to 13.0-14.5 p.p., indicating gradual rehabilitation of loan portfolios. ROA stabilises at 1.2-1.5p.p., while CAR returns to controlled levels of 19.0-21.0 p.p., providing sufficient capital to sustain ongoing operations. Currency volatility falls to 8-12%, and annual capitalisation rates reach 5-7%, signalling a revival of investor confidence.

Implementing security-oriented management models can reinforce these trends by improving flexibility in risk management, compliance systems, and human resource adaptation.

The active recovery scenario demonstrates the most favourable conditions for financial security. NPLs are reduced to 7.0-8.5p.p., and ROA rises to 3.0-3.4p.p., indicating effective use of the resource base. CAR increases to 22.5-24.0p.p., ensuring a strong capacity to absorb risks and support credit expansion. Currency fluctuations fall to below 5%, evidencing monetary market stabilisation, while capitalisation accelerates to 10-13% annually. This scenario provides the most conducive environment for the large-scale implementation of security-oriented management practices, ensuring systemic resilience through the integration of cybersecurity, anti-crisis human resource strategies, reputation monitoring and legal predictability.

To complement the scenario analysis, regression modelling was used to examine the direction and relative strength of the association between the corporate security index and selected financial stability indicators. Standardised coefficients were estimated under the three scenario settings to compare the sensitivity of financial indicators under conditions of prolonged crisis, partial stabilisation and active recovery. The resulting coefficients are interpreted as exploratory sensitivity measures rather than causal effects and are presented in Table 7.

Table 7. Standardised sensitivity coefficients between corporate security and financial stability indicators under alternative scenarios

Financial indicator	Scenario 1: Protracted crisis	Scenario 2: Partial stabilisation	Scenario 3: Active recovery
ROA	+0.47	+0.62	+0.78
CAR	+0.33	+0.51	+0.66
NPL	-0.52	-0.61	-0.70
Capitalisation growth	+0.28	+0.49	+0.67
Liquidity	+0.39	+0.54	+0.72

Note: authors' calculations based on the National Bank of Ukraine (2025), Fojcik (2024), Fitch Ratings (2024)

The modeling results show that banks' financial indicators are highly sensitive to changes in the integral level of corporate security across all scenarios. In particular, the increase in ROA, with a coefficient of +0.78 in the active recovery scenario, shows that higher levels of corporate security are associated with higher profitability indicators. Similarly, CAR and capitalisation rates show

significant positive dynamics with rising levels of corporate security, reflecting the strengthening of banks' resource base and their capacity for autonomous financing. The negative correlation with NPL confirms the effectiveness of corporate control mechanisms in reducing credit risks. Liquidity proved to be the most dynamic parameter: under conditions of high corporate security, it increased

most substantially, indicating banks' adaptive capacity to maintain solvency even under stress.

The combined results of scenario and econometric modeling confirm that the introduction of a security-oriented management model generates considerable effects not only at the level of individual institutions, but also at the macro-financial level. The established regression relationships demonstrate the statistical association between the corporate security profile and key financial stability parameters of banks – profitability, asset quality, capitalization and liquidity – with the strength of these effects increasing under conditions of economic growth. Policymakers can incorporate these interdependencies into banking regulatory policy, particularly when designing indicative mechanisms for assessing financial stability. The findings thus reaffirm the role of corporate security as a critical component of financial architecture during structural transformation and post-war economic recovery.

DISCUSSION

The results of the analysis revealed significant interbank differentiation in the level of corporate security, which stemmed from differences in organisational structure, ownership type, risk management practices, and the depth of digital transformation. The analysis showed that institutions with high integral security index values also demonstrated stable key financial indicators and reduced sensitivity to external destabilizing factors, as confirmed by scenario modeling. The identified correlation between the balance of functional security blocks and institutions' adaptability to changes in the macro-financial environment validated the application of the multidimensional assessment model.

The developed typology enabled the stratification of banking institutions by the level of comprehensive security, thereby identifying systemic areas of vulnerability and creating an empirical basis for constructing adaptive scenarios in the banking sector. A multidimensional model of corporate security, encompassing key risk management blocks, proved effective under conditions of macro-financial instability. Zan (2024) proposed a similar approach, highlighting the importance of integrating internal management mechanisms with external regulatory factors. His work underscores the need

for consistency between institutional processes and preventive monitoring of systemic risks as prerequisites for financial stability. The correlation of results confirmed the feasibility of implementing such a model in banking security management.

The stratified analysis further showed that the effectiveness of risk management depends not only on asset size or ownership form, but also on institutions' capacity to adapt amid external turbulence. Kacicka (2023) also addressed strategic flexibility in management decisions, using the food industry as an example to examine the possibility of combining strategic planning with innovative risk management. The findings confirmed the universality of this approach for sectors highly sensitive to environmental changes, including the banking system. The study found that the ability to restructure management processes rapidly plays a decisive role in enhancing overall institutional security.

As part of the study of systemic threats, it was established that traditional regulatory tools do not adequately respond to multi-vector risks. The findings of Ellis et al. (2022) confirmed the need to improve methods of measuring systemic risks, considering transformational dynamics of the financial environment. Their work emphasises that the transition to a comprehensive measurement of cross-functional risks is critical for modern regulatory practice. The results of this study provided an empirical basis for developing such tools, highlighting the need to expand traditional risk assessment methodology.

The theoretical framework set out by Schweizer (2019) formed the foundation for a deeper understanding of systemic threats as phenomena of complex adaptive systems. Within the scope of this research, such an approach allowed for a reorientation of the analytical focus from the analysis of individual financial indicators to their interaction with the structural parameters of corporate governance. Including personnel, information, and legal security enabled the construction of a holistic model of multi-component security for banking institutions. This ensured the integration of qualitative and quantitative variables in developing the integral corporate security index.

The structural-functional approach used in the study aligns with the concept presented by Bacciu et al. (2022), which demonstrated the need for systemic

risk management that incorporates interdisciplinary determinants. In their work, fire risk modeling was carried out; however, this study adapted the approach to the banking sector by interpreting the cumulative effects of security breaches. This adaptation made it possible to consider both the physical component and the informational and cyber aspects of institutional functioning, which is particularly important amid post-crisis economic turbulence.

The analysis of digital factors for enhancing management efficiency revealed that the digital transformation of banking processes positively influences the operational contour of corporate security systems. These findings align with the case study by Bueno et al. (2024), which examined digitalization as a tool for strengthening risk management and internal control. The study found that banks with a high level of digital integration had lower transaction costs, more efficient data-processing procedures, and greater adaptability to external challenges.

Scenario modeling results also showed that digital infrastructure is a key factor in shaping banks' institutional resilience to macro-financial and regulatory shocks. A similar relationship between technological adaptation and vulnerability reduction was identified by Zaman et al. (2023) in the context of logistics chains in the e-commerce sector. In the banking sector, analogous mechanisms were observed in the assessment of organisational flexibility, which ensured the continuity and stability of processes even under intensifying external risks. The decisive role of digital tools in this process makes the technological component an integral element of the architecture of multidimensional corporate security.

The analysis also examined how artificial intelligence (AI) tools improve the efficiency of information and cybersecurity systems. According to the framework proposed by Rodrigues et al. (2022), a cognitive model of interaction between AI, digital transformation, and cybersecurity strengthens the integration of technological solutions into the protective infrastructure of financial institutions. Within the present study, this approach was adapted to the corporate security model by incorporating the level of information security as one of its functional components.

In examining operational efficiency, a positive correlation was recorded between the degree of

digital transformation and indicators of financial inclusion. The findings of Mavlutova et al. (2023) confirm that the expansion of digital services enhances the accessibility of banking services, which in turn contributes to the resilience and stability of the financial system. Consistent with this, the present study established that institutions with more advanced digital infrastructures demonstrated higher levels of operational efficiency, thereby reducing their vulnerability to financial risks.

The importance of information security as a determinant of user trust in banking services was reinforced by the study of Zhang et al. (2023), which found that the level of cybersecurity significantly influences customers' willingness to adopt fintech solutions. The analysis of corporate security indicators within this research similarly revealed a positive relationship between the level of information security and the composite resilience index, corroborating earlier scientific findings.

The type of bank influences how security management models are implemented. In particular, Raouf and Ahmed (2022) demonstrated that the effectiveness of risk management systems varies considerably between traditional and Islamic banks in the GCC countries. They concluded that the clear regulation of internal control procedures, inherent in specialised institutional structures, has a positive impact on institutional stability. The present study observed a similar trend, where banks with formalized internal audit policies showed greater resilience.

The analysis of information support for management processes showed that effective digital management accounting systems enhance transparency and reduce operational risks. Oudat (2021) substantiated the relationship between the quality of information systems and banking stability. The criteria applied in this study confirmed higher levels of information security in banks that had introduced modern analytical platforms and automated compliance mechanisms.

Intellectual capital and human resource policy were also identified as key components of corporate security. Ullah et al. (2021) found that the existence of a developed knowledge management system and structured staff training is positively correlated with financial stability. The present analysis confirmed similar relationships: banks with higher human resource security scores showed stronger adaptability

under risk scenarios, underscoring the importance of human capital in security management strategies.

The legal component – encompassing regulatory compliance and digital compliance control – was likewise recognised as a critical dimension of banking security. Chao et al. (2022) proposed a taxonomy of RegTech tools for monitoring financial stability, with particular emphasis on automated risk detection and adherence to regulatory standards. This study adopted a comparable approach, evaluating legal metrics as a distinct block of the corporate security model. This enabled the identification of a direct link between the degree of regulatory control and institutional resilience to supervisory challenges. Integrating digital compliance tools into risk management frameworks provided an additional protective layer against systemic regulatory failures.

In the economic security block, the study found that financial diversification is a significant factor in the stability of banking institutions in a changing environment. Xie et al. (2022) substantiated the importance of income diversification strategies as a means of enhancing financial stability. The results confirmed the hypothesis: banks with a broad product portfolio and a diversified client base showed higher levels of economic and financial security. Such diversification enabled greater flexibility of financial policy and a more effective response to external crises.

Financial forecasting was identified as one of the key tools of strategic planning under conditions of macro-financial instability. Kumar (2023) showed that multifactor forecasting models significantly influence the quality of management decisions in the financial sector. In this study, a scenario-based approach to assessing the integral corporate security index was implemented, enabling identification of potential risk configurations and evaluation of banking institutions' resilience to changes in the external environment. This model provided the foundation for developing preventive strategies for financial adaptation.

Digital automation tools, analysed by Singireddy et al. (2024), were assessed as critically important for transforming banks' management practices. The authors highlighted the role of smart automation, secure access systems and predictive intelligence in optimising risk management processes. The results confirmed that institutions with higher digital integration achieved stronger technological

and information security, which contributed to enhanced overall corporate resilience. Adopting these technologies ensured consistent management decisions and minimized the influence of the human factor.

In the context of global economic transformations, uncertainty management as a strategic balancing tool has become particularly important. Iriani et al. (2024) emphasised the need to integrate qualitative analyses of the external environment with quantitative methods in order to improve the accuracy of strategic decisions. In this study, this concept was operationalized through a multi-level security assessment model, enabling risk evaluation at the intersection of functional blocks. This approach supported the development of an adaptive corporate governance system relevant to the conditions of a transformational economy.

Modern research has devoted considerable attention to the role of digital tools in strengthening the financial stability of banking institutions. Challa et al. (2024) examined the impact of technological solutions on investment stability and the reduction of transaction risks. The authors proposed a multi-level model combining cybersecurity platforms, automated monitoring protocols and elements of predictive analysis. This concept aligns with the conclusions of the present study, which recorded high values of information and technological security in banks with a developed digital architecture.

In the context of intelligent risk management, this study analyzed Vyas's (2025) approach, emphasizing the use of AI to develop cognitive threat management systems. The model integrated adaptive self-learning algorithms designed to improve decision-making accuracy in financial forecasting. The findings confirmed the need to develop a multi-vector security system that reflects the multifactorial nature of risks during the post-crisis reconfiguration of the banking system. This approach provided an empirical basis for assessing the effectiveness of intelligent elements in institutions' strategic adaptation.

The research confirmed the feasibility of using a security-oriented management model as a holistic response to threats from structural shifts in the macro-financial environment. The integral corporate security index, developed from eight functional blocks, revealed internal differentiation among banks based on digital transformation, strategic

flexibility, and financial resilience. The analysis identified areas of heightened risk and demonstrated structural heterogeneity in approaches to security management. The applied stratified assessment methodology proved effective in comparing institutions with varying levels of technological maturity.

The correlation between the results and findings from digital transformation, intelligent risk management, RegTech, and strategic financial forecasting underscores the relevance of the chosen approach. This interdisciplinary consistency highlights the need to improve further banking management models aimed at preventing systemic risks in unstable environments. Such models should integrate quantitative analysis, technological diagnostics, and scenario simulations, thereby ensuring the flexibility and adaptability of the banking sector under conditions of macro-financial transformation.

CONCLUSIONS

As part of the study, a methodological model for stratifying banking institutions by the level of corporate security was developed and tested, based on the construction of an integral index comprising eight functional blocks: financial, information, economic, physical, personnel, technological, reputational and legal security. On the basis of the obtained values of the integral indicator, the ten largest banks of Ukraine were stratified. The assessment showed significant differences among Ukrainian banks in corporate security levels. Institutions with higher integrated security profiles showed more balanced performance across functional components, whereas lower-security institutions demonstrated greater internal disparities requiring targeted managerial improvement. The identified asymmetries between individual security components indicated internal imbalances in management practices related to integrating security functions.

Scenario modeling produced three alternative trajectories of macro-financial development: a protracted crisis, partial stabilization, and active reconstruction. For each scenario, the levels of problem debt, asset profitability, capital adequacy, currency volatility and capitalisation were determined. Scenario modeling showed that strengthening corporate security is associated with

improved financial stability, including reduced credit risk, higher profitability potential, and greater resilience under favorable recovery conditions. This dependence confirmed the strategic importance of strengthening functional security mechanisms for enhancing the financial stability of banking institutions.

The study has certain limitations. It is limited to a sample of only the ten largest banks, lacks complete data to assess some components of corporate security, relies on estimation assumptions in scenario modeling, and is affected by changes in the regulatory environment that affect the relevance of certain indicators. Further research should therefore expand the sample to include medium- and small-scale institutions, as well as adapt the model for regional and international comparative analysis. Another important direction is to integrate regulatory supervision indicators and explore relationships between digital transformation, the level of compliance control, and scenario adaptability. Applying machine learning methods to build predictive corporate security models that account for dynamic interactions among functional blocks in a changing financial environment also appears promising.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: HF; research design: AP, HF, OB, AS and AA; data collection: OB; analysis and interpretation: AS and AA; writing draft preparation: AP, HF, OB, AS and AA; supervision: AP; correction of article: AP, HF, OB, AS and AA; proofread and final approval of article: AP, HF and AA. All authors have read and agreed to the published version of the manuscript.

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Forecasting Tunisian Stock Market Dynamics Using Neural Networks

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ABSTRACT

Predicting stock market dynamics remains challenging, especially in emerging and frontier markets, where high uncertainty, limited liquidity, and information asymmetries can reduce the robustness of predictive models. This study aims to compare the forecasting performance of Artificial Neural Networks (ANN) and Long Short-Term Memory (LSTM) models for the TUNINDEX20 against a naïve persistence benchmark. The information base consisted of daily data on the TUNINDEX20 index of the Tunis Stock Exchange from February 6, 2012, to December 31, 2024, including 1,915 observations. The sample was divided chronologically into a training set of 1,532 observations and a test set of 383 observations. The results showed that the artificial neural network slightly outperformed the long short-term memory model in terms of key accuracy metrics: for the first model, MAE was 12.06, RMSE was 15.92, MAPE was 0.31%, MASE was 1.0769, R^2 was 0.9912, and the accuracy of predicting the direction of index movement was 53.91%. At the same time, the naïve model showed slightly lower forecast errors (MAE = 11.76; RMSE = 15.82), and the Diebold–Mariano test did not reveal a statistically significant advantage of ANN over the naïve model ($p = 0.7285$). The results obtained show that a more complex architecture does not automatically provide an advantage in forecasting TUNINDEX20. Future research could include adding technical indicators and macro-financial variables, testing models in other emerging markets, and applying adaptive and hybrid forecasting methods.

KEYWORDS: Stock Market, Neural Network, Digitalization, Investment Strategy, Financial Decision, Financial Forecasting, Tunisia

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Прогнозирование динамики фондового рынка Туниса с использованием нейронных сетей

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АННОТАЦИЯ

Прогнозирование динамики фондового рынка остается сложной задачей, особенно для развивающихся и пограничных рынков, где высокая неопределенность, ограниченная ликвидность и информационные асимметрии могут снижать устойчивость прогнозных моделей. Цель данного исследования заключается в сравнении прогностической эффективности моделей искусственных нейронных сетей и долгой краткосрочной памяти при прогнозировании индекса TUNINDEX20 с наивной моделью персистентности. Информационную базу составили ежедневные данные индекса TUNINDEX20 Тунисской фондовой биржи за период с 6 февраля 2012 г. по 31 декабря 2024 г., включающие 1 915 наблюдений. Выборка была разделена в хронологическом порядке на обучающую часть из 1 532 наблюдений и тестовую часть из 383 наблюдений. Результаты показали, что искусственная нейронная сеть несколько превосходит модель долгой краткосрочной памяти по основным показателям точности: для первой модели MAE составил 12.06, RMSE – 15.92, MAPE – 0.31%, MASE – 1.0769, R^2 – 0.9912, а точность прогнозирования направления движения индекса – 53.91%. Вместе с тем наивная модель показала немного более низкие ошибки прогноза (MAE = 11.76; RMSE = 15.82), а тест Диболда–Мариано не выявил статистически значимого преимущества ANN над наивной моделью ($p = 0.7285$). Полученные результаты показывают, что более сложная архитектура не обеспечивает автоматического преимущества в прогнозировании TUNINDEX20. Перспективы дальнейших исследований связаны с включением технических индикаторов и макрофинансовых переменных, тестированием моделей на других развивающихся рынках, а также применением адаптивных и гибридных методов прогнозирования.

КЛЮЧЕВЫЕ СЛОВА: фондовый рынок, нейронная сеть, цифровизация, инвестиционная стратегия, финансовое решение, финансовое прогнозирование, Тунис

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INTRODUCTION

Forecasting stock market fluctuations remains a major challenge for investors, policymakers, and financial institutions, particularly in emerging and frontier markets characterized by heightened uncertainty, persistent information asymmetries, and structural market imperfections (Boubaker et al., 2022). These features amplify the complexity of asset price dynamics and make financial market prediction especially demanding.

Within this context, the TUNINDEX20, comprising the twenty largest and most liquid firms listed on the Tunis Stock Exchange (BVMT), serves as a key benchmark for assessing the efficiency and overall dynamics of the Tunisian financial market. Beyond reflecting domestic stock market performance, the index also provides valuable insights into the broader state of the Tunisian economy. Consequently, the ability to forecast the TUNINDEX20 is of considerable importance for institutional investors, portfolio managers, and economic decision-makers seeking to optimize portfolio allocation and risk management strategies.

For decades, financial time-series forecasting has been dominated by traditional econometric approaches, particularly linear and autoregressive models (Box et al., 2008). However, a growing body of literature has highlighted the limitations of these methods when confronted with the nonlinear, non-stationary, and noisy nature of financial data, as well as the complex interactions among market variables (Zhang et al., 1998; Tashman, 2000). These limitations reduce their ability to accurately capture the underlying dynamics of financial markets, especially during periods of heightened volatility and structural change (Kaygın et al., 2026).

In response to these challenges, artificial intelligence techniques and particularly Artificial Neural Networks (ANN) have progressively emerged as powerful and flexible alternatives for financial forecasting. Unlike conventional econometric models, ANN architectures can model highly nonlinear relationships without imposing restrictive assumptions regarding data distribution or functional form. Their ability to extract hidden patterns and learn complex representations directly from financial time series has led to significant advances in predictive performance (Goodfellow et al., 2016; Sezer et al., 2020). Long Short-Term

Memory (LSTM) networks, which incorporate memory and gating mechanisms, represent a major advancement over traditional recurrent neural networks by enabling the effective modelling of long-term temporal dependencies (Hochreiter & Schmidhuber, 1997; Fischer & Krauss, 2018). Their distinctive architecture makes them particularly suitable for financial time-series forecasting, where past market dynamics may exert persistent effects on future price movements.

A review of the empirical literature on the Tunis Stock Exchange reveals evidence discussing the extent to which the market adheres to informational efficiency, particularly in its weak form (Bekaert & Harvey, 1997). Previous studies document the presence of temporal dependencies, persistent volatility, gradual adjustment to new information, and heightened sensitivity to external shocks, suggesting that information may not be instantaneously nor perfectly incorporated into asset prices (Fakhfekh et al., 2021). These features appear especially pronounced in a developing market environment characterized by uneven liquidity, sectoral concentration, and significant informational asymmetries. However, evaluating whether deep learning models can consistently generate risk-adjusted abnormal returns over standard random-walk baselines remains an open empirical question.

In this context, the growing interest in artificial intelligence and machine learning techniques appears fully justified. These approaches are particularly attractive because of their ability to process large volumes of data, capture nonlinear interactions, and identify memory and regime effects that conventional econometric models often fail to incorporate effectively (Henrique et al., 2019; Nabipour et al., 2020). This study aims to compare the forecasting performance of Artificial Neural Networks (ANN) and Long Short-Term Memory (LSTM) models for the TUNINDEX20 against a naïve persistence benchmark.

The empirical analysis conducted in this study relies on daily TUNINDEX20 data covering the period from 2012 to 2024, comprising 1,915 daily observations retrieved from the official BVMT database. The findings indicate that both ANN and LSTM architectures can model the dynamics of the Tunisian stock market with a high degree of predictive accuracy. To rigorously assess their practical value, both models are benchmarked against

a naïve persistence model (Random Walk) and evaluated through formal statistical tests, including the Diebold–Mariano and Ljung-Box diagnostic tests.

A detailed comparative analysis shows that the parsimonious ANN model performs slightly better than the LSTM architecture across several forecasting metrics, with a lower MAE (12.06 versus 12.23) and MAPE (0.31% versus 0.32%). However, the naïve persistence benchmark achieves marginally lower level-forecast errors (MAE = 11.76; MAPE = 0.30%), indicating that neither neural network provides a clear advantage in index-level prediction. The ANN model nevertheless demonstrates better directional forecasting performance than the LSTM model, with directional accuracy of 53.91% compared with 51.20% for LSTM. Formal Diebold–Mariano tests confirm that the forecasting differences are not statistically significant relative to the naïve persistence benchmark, suggesting that the high R^2 values largely reflect strong price-level persistence rather than a superior predictive edge. In addition, the ANN residuals show no significant autocorrelation at the 5% level, whereas the LSTM model exhibits significant residual autocorrelation ($Q = 36.10$, $p = 0.0001$), which may indicate remaining temporal structure not fully captured by the recurrent model. A one-sided binomial test for ANN directional accuracy yields $p = 0.0730$, providing only marginal evidence of directional predictability at the 10% significance level. Taken together, these findings suggest that the simpler ANN architecture may offer greater stability than the more complex LSTM model, while its predictive advantage over a naïve persistence benchmark remains limited.

LITERATURE REVIEW

The Efficient Market Hypothesis (EMH) represents one of the foundational pillars of modern financial theory, as it directly addresses the mechanisms of price formation and the predictability of stock market returns. Early reflections on the random nature of price fluctuations can be traced back to the pioneering work of Louis Bachelier (1900), who introduced the idea that asset prices evolve according to an unpredictable stochastic process. Although his contributions remained largely overlooked for several decades, they established the theoretical foundations for subsequent research on market dynamics.

It was not until the 1960s that the behaviour of financial asset prices became the subject of systematic empirical investigation, particularly through the work of Paul Samuelson (1965), who formally linked available information to price movements. However, the most influential formulation of market efficiency was provided by Eugene Fama (1970), who defined an efficient market as one in which asset prices fully and instantaneously reflect all available information. Under this framework, the possibility of consistently generating abnormal profits is theoretically eliminated, since any new information is immediately incorporated into market prices.

Despite its dominant role in academic finance, the EMH has been increasingly challenged since the 1980s by a growing body of empirical evidence documenting persistent deviations from its theoretical predictions (Bekaert et al., 2023). These market anomalies include temporal dependencies in returns, overreaction and underreaction to new information, as well as the existence of abnormal returns that cannot easily be explained within a strictly efficient market framework.

Such phenomena appear even more pronounced in emerging and frontier markets, where informational imperfections tend to be more significant (Boubaker et al., 2022; Kaygin et al., 2026). These markets are often characterized by limited transparency, incomplete information dissemination, illiquidity, and specific institutional constraints (Fakhfekh et al., 2021). In such environments, asset prices may fail to fully and immediately incorporate all relevant information, thereby creating potential opportunities for short-term pattern recognition and financial prediction. However, establishing whether non-linear predictive algorithms genuinely generate statistically significant outperformance over standard random-walk baselines remains essential to validate claims of market predictability.

Traditional econometric techniques, particularly ARIMA and GARCH models, have long served as the primary tools for analysing and forecasting financial time series. The ARIMA framework, widely associated with the Box–Jenkins methodology (Box et al., 2008), assumes that temporal dependencies can be adequately captured through linear relationships among past observations of a series. In contrast, the GARCH model proposed by Tim Bollerslev (1986) was developed to model conditional heteroskedasticity by accounting for the

time-varying nature of volatility, a well-established characteristic of financial markets.

Despite their widespread application, these models exhibit important limitations when applied to complex financial series. In particular, they rely on restrictive assumptions such as linearity and stationarity that are rarely fully satisfied in real-world financial environments (Tashman, 2000). Financial markets are inherently characterized by nonlinear dynamics, structural breaks, regime shifts, and complex interactions among variables that cannot be fully captured through conventional parametric specifications (Tsay, 2005; Sezer et al., 2020).

These limitations become even more pronounced in emerging and frontier markets, where institutional conditions, external shocks, and structural transformations exert a substantial influence on price dynamics (Büyüksahin & Ertekin, 2019). Limited liquidity, informational asymmetries, and irregular volatility patterns further complicate the modelling of market behaviour using linear approaches, thereby reducing the predictive power of traditional econometric models.

By contrast, machine learning approaches are capable of learning directly from data without requiring predefined functional forms. The inability of conventional models to adequately capture nonlinearities and complex temporal dependencies has therefore stimulated growing interest in alternative forecasting techniques. However, evaluating whether non-linear architectures genuinely outperform simple persistence baselines requires rigorous benchmarking against a naïve random-walk model to account for index-level persistence. Within this context, neural network-based models have emerged as promising tools, particularly for emerging markets whose structural characteristics differ substantially from those of developed economies.

Among these approaches, ANN have been extensively employed because of their strong nonlinear approximation capabilities. The seminal works of George Cybenko (1989) and Kurt Hornik et al. (1989) demonstrated that multilayer neural networks can approximate virtually any continuous function, making them particularly suitable for modelling financial time series. A substantial body of empirical research has shown that ANN-based models frequently outperform traditional econometric approaches in environments characterized by strong nonlinearities and structural instability (Goodfellow et al., 2016).

Nevertheless, conventional feedforward ANN architectures suffer from an important limitation: their inability to explicitly model long-term temporal dependencies. This shortcoming motivated the development of recurrent neural network architectures, particularly LSTM networks introduced by Sepp Hochreiter and Jürgen Schmidhuber (1997). Through their internal memory cells and gating mechanisms, LSTM models can capture complex sequential dependencies, making them especially well-suited for financial time-series analysis.

Recent empirical studies increasingly highlight the use of deep learning techniques in financial forecasting. For instance, Fischer and Krauss (2018) demonstrate that LSTM architectures improve stock return prediction compared with conventional forecasting models. Similarly, the comprehensive literature review conducted by Sezer et al. (2020) emphasizes the ability of deep learning methods to capture nonlinear financial structures and enhance predictive accuracy. Gu et al. (2020) further show that machine learning approaches can uncover complex relationships that remain undetected by traditional econometric specifications, thereby improving overall forecasting performance (Nabipour et al., 2020; Boubaker et al., 2022).

Additional comparative studies have reinforced the predictive relevance of neural network-based approaches. For example, Shahrour and Dekmak (2024) report that deep learning techniques, particularly ANN and LSTM models, outperform conventional machine learning methods such as Support Vector Regression (SVR) in stock price prediction tasks. Likewise, Varshney and Srivastava (2023), in a comparative analysis between ANN and ARIMA models applied to the NIFTY 50 index over the 2005–2019 period, conclude that ANN architectures achieve superior forecasting accuracy, suggesting a greater ability to capture the complex dynamics underlying stock price fluctuations (Büyüksahin & Ertekin, 2019).

However, despite these advances, most empirical studies remain concentrated on developed markets, which are generally characterized by high liquidity and superior information quality. Findings obtained in such environments cannot necessarily be generalized to emerging markets, where price dynamics are strongly influenced by structural factors such as informational asymmetries, limited market depth, and institutional constraints (Fakhfekh et al., 2021).

Although the application of deep learning techniques to emerging markets has attracted growing academic interest, the Tunisian stock market remains largely underexplored. To the best of our knowledge, no prior study has applied ANN and LSTM models to the TUNINDEX20 index for forecasting purposes. Existing research on the Tunisian market has primarily relied on traditional econometric approaches focused on market efficiency, informational dynamics, and temporal anomalies.

Within this context, the comparative performance of ANN and LSTM models in an emerging market environment remains an open empirical question. In particular, the superiority of more sophisticated architectures such as LSTM cannot be assumed in markets characterized by strong price persistence and relatively low liquidity. Therefore, comparative evaluations should ensure consistent model specifications, including identical look-back windows, and benchmark deep learning forecasts against a naïve persistence model to distinguish genuine predictive gains from underlying index persistence. This highlights the need for rigorous model evaluation in relatively underexplored markets such as Tunisia.

DATA AND METHODOLOGY

This study is based on daily observations of the TUNINDEX20, the benchmark index of the Tunis Stock Exchange (BVMT). The historical market data were obtained directly from the official database

of the Tunis Stock Exchange (BVMT, 2025). The total sampling period spans from February 6, 2012 to December 31, 2024. After removing non-trading days, holidays, and missing entries, the final clean dataset consists of 1,915 daily observations.

The forecasting task is defined as predicting the daily closing index value for the next trading session ($t+1$). Although the original market data contain standard OHLCV variables (Open, High, Low, Close, and Volume), both the ANN and LSTM models use only the lagged historical sequence of the daily closing price as input. Specifically, both models utilize a fixed look-back window of 10 previous trading sessions ($t-9, t-8, \dots, t$) to predict $t+1$, thereby ensuring full model comparability and eliminating specification bias. The selected multi-year period covers several major macroeconomic regimes, including the post-revolution recovery period, subsequent market stabilization, the COVID-19 pandemic shock, and the post-pandemic recovery phase. The original dataset contains the following variables:

- (1) Date: trading session date;
- (2) Open: opening price;
- (3) High: highest price of the trading session;
- (4) Low: lowest price of the trading session;
- (5) Close: closing price (target variable for forecasting);
- (6) Volume: daily trading volume.

Figure 1 displays the historical sequence of daily TUNINDEX20 closing prices over the 2012–2024 observation period.

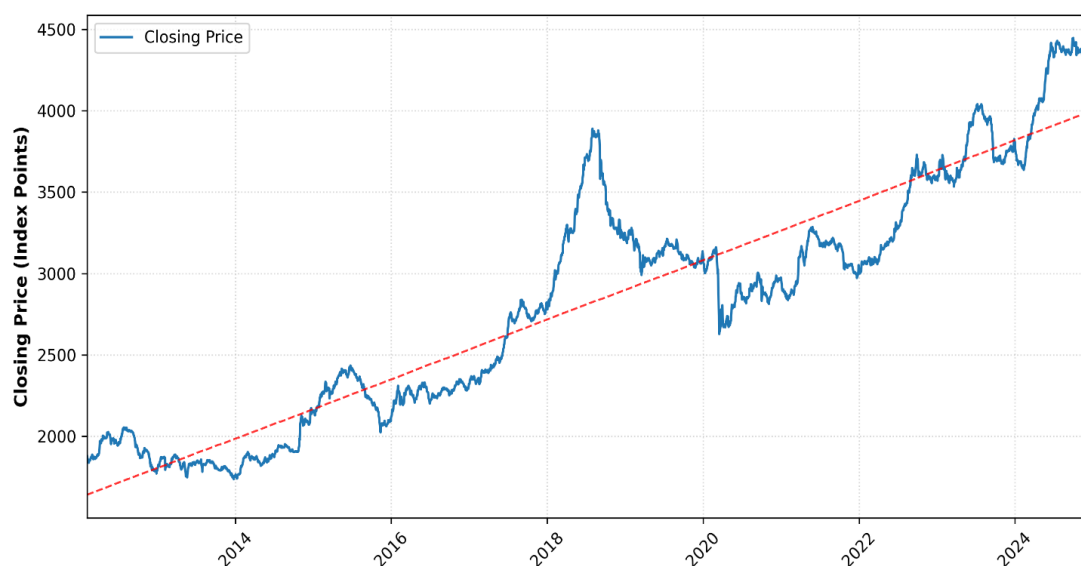


Figure 1. Historical evolution of the TUNINDEX20 closing prices for 2012–2024

As illustrated in Figure 1, the index exhibits a broadly upward trend punctuated by moderate fluctuations, reflecting the structural characteristics typically associated with an emerging and frontier market environment. Starting from a baseline of 1,876.10 index points in February 2012, the TUN-INDEX20 reached an all-time peak of 4,384.00 index points by late 2024, representing an overall cumulative variation of +133.4%.

This pattern may be linked to relatively limited market liquidity, as evidenced by the moderate and irregular trading volumes observed throughout the sample period. Such behaviour is consistent with the structural features commonly documented in emerging markets, including shallow market depth, sectoral concentration, and persistent informational inefficiencies (Bekaert et al., 2023; Fakhfekh et al., 2021). The prominent upward drift over the sample period further underscores the existence of strong price-level persistence, reinforcing the critical necessity of evaluating predictive neural networks against a naïve random-walk baseline.

Data preprocessing represents a critical stage in any machine learning or deep learning framework, particularly in financial time-series forecasting, where predictive performance depends as much on preprocessing rigor as on model architecture selection. The raw dataset exhibited formatting characteristics associated with the European numerical convention, including commas used as decimal separators and periods used for thousand delimiters. A systematic cleaning procedure was therefore implemented, involving the removal of unnecessary spaces in column names, the replacement of commas with decimal points, and the conversion of all variables into appropriate numerical formats.

Neural networks do not possess inherent memory mechanisms in their standard form. Consequently, the dataset was transformed into a supervised learning problem using a sliding-window approach.

To ensure full structural comparability between architectures and eliminate specification bias, a fixed 10-day look-back window ($t-9, t-8, \dots, t$) was adopted for both the ANN and LSTM models to predict the index level at $t+1$. Standardizing the temporal input space guarantees that performance differences reflect true architectural capabilities rather than discrepancies in historical input sequence length.

Feature scaling is an important preprocessing step in neural network training because it can improve numerical stability and facilitate model convergence. Following Nayak et al. (2014), the TUN-INDEX20 closing values were normalized using Min-Max scaling to the $[0, 1]$ interval (1):

$$X_{\text{norm}} = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \quad (1)$$

where:

X – the original TUNINDEX20 closing value;

X_{norm} – the normalized value;

$X_{\min}, X_{\max}$ – the minimum and maximum closing values estimated exclusively from the training set.

The dataset was chronologically divided into a training set comprising 80% of the observations (1,532 daily observations) and an out-of-sample test set comprising the remaining 20% (383 daily observations). The training set was used for model estimation and learning, while the test set was reserved exclusively for evaluating predictive performance on unseen data. The chronological order of the observations was preserved throughout the partitioning process to prevent temporal information leakage between the training and testing periods. This approach is consistent with Tashman (2000), who emphasizes the importance of out-of-sample evaluation using observations excluded from model estimation.

Table 1 summarizes the hyperparameters selected for the ANN model.

Table 1. Summary of ANN model hyperparameters

Component	Parameter	Value
Architecture	Number of hidden layers	2
	Neurons (layer 1)	32
	Neurons (layer 2)	16
	Hidden activation	ReLU
	Output activation	Linear
Regularization	Dropout	0.2
	Early stopping	30

Optimization	Optimizer	Adam
	Learning rate	0.001
	Batch size	32
	Epochs	100
Data	Time window	10 days
	Validation Split	10%

Note: compiled by the authors

The configuration was chosen to balance predictive accuracy, model stability, and generalization while limiting the risk of overfitting.

As shown in Table 1, the ANN architecture consists of two hidden layers with 32 and 16 neurons, respectively. Each hidden layer uses the Rectified Linear Unit (ReLU) activation function (2):

$$f(x) = \max(0, x) \quad (2)$$

where:

x – the input to the neuron;

$f(x)$ – the output of the ReLU activation function.

A linear activation function is used in the sin-

gle-neuron output layer to predict the next-day closing index value ($t + 1$). To reduce overfitting, a dropout rate of 0.2 is applied between the hidden layers. Early stopping with a patience of 30 epochs is used based on a 10% validation subset of the training data.

The model is trained using the Adam optimizer with an initial learning rate of 0.001, a batch size of 32, and a maximum of 100 epochs. A fixed 10-day look-back window ($t, -, 9 \dots t$) is used to predict the closing index value at $t + 1$, corresponding approximately to two trading weeks of historical information.

Table 2 provides a summary of the hyperparameters retained for the LSTM architecture following a systematic tuning procedure.

Table 2. Summary of LSTM model hyperparameters

Component	Parameters	Value
Architecture	Number of LSTM layers	3
	LSTM Neurons 1	100
	LSTM Neurons 2	100
	LSTM Neurons 3	50
	Return sequences (1-2)	True
	Return sequences (3)	False
	LSTM Activation	tanh
	Intermediate dense layer	25 neurons (ReLU)
	Output activation	Linear
Regularization	Dropout (LSTM)	0,3
	Dropout (dense)	0,2
	Early stopping patience	30
Optimization	Optimizer	Adam
	Learning rate	0,001
	Batch size	32
	Maximum epochs	200
Data	Time window	10 days
	Features	1 (CLOSE)
	Validation Split	10%

Note: compiled by the authors

As detailed in Table 2, the deep architecture consists of three stacked LSTM layers comprising 100, 100, and 50 units, respectively. The first two LSTM layers return full temporal sequences (`return_sequences = True`) to feed subsequent recurrent structures, whereas the third layer outputs a condensed vector (`return_sequences = False`). Hyperbolic tangent (`tanh`) activation functions are utilized within the recurrent cells, followed by an intermediate Dense layer of 25 neurons with `ReLU` activation.

To mitigate overfitting, a Dropout rate of 0.3 is applied across the LSTM layers, combined with a 0.2 Dropout rate on the dense layer. Optimization is conducted using the Adam optimizer with a learning rate of 0.001 and a batch size of 32 over a maximum of 200 epochs, monitored by an Early Stopping mechanism set to a patience threshold of 30 epochs on a 10% validation split. To maintain strict alignment with the ANN setup and isolate architectural effects, the input sequence is set to a 10-day look-back window (`t-9, t-8, ..., t`) using the daily closing price to forecast `t+1`.

To evaluate whether the ANN and LSTM models provide forecasting gains beyond simple index persistence, a naïve persistence model was used as a benchmark. In financial time-series forecasting, index levels often exhibit strong persistence, which may result in high goodness-of-fit measures even when a model provides limited incremental forecasting value.

The naïve persistence model assumes that the best forecast of the next trading session's closing index value is the most recently observed value (3):

$$\hat{Y}_{t+1} = Y_t \quad (3)$$

where:

Y_t – the observed TUNINDEX20 closing value at time t ;

$\hat{Y}_{t+1}$ – the forecast closing value for the next trading session.

By comparing the ANN and LSTM forecasts with this benchmark, it is possible to assess whether the neural network models provide predictive gains beyond simple persistence. The naïve model also provides the reference benchmark for the Diebold–Mariano tests of forecast accuracy.

Forecasting performance was evaluated using Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), Mean Absolute Percentage Error

(MAPE), Mean Absolute Scaled Error (MASE), the coefficient of determination (R^2), and Directional Accuracy (DA). MAE, RMSE, and MAPE measure the magnitude of forecasting errors, while R^2 reflects the degree of correspondence between observed and predicted index values.

MASE evaluates forecast accuracy relative to an in-sample naïve benchmark (4):

$$\text{MASE} = \frac{\text{MAE}}{\frac{1}{n-1} \sum_{i=2}^n |Y_i - Y_{i-1}|} \quad (4)$$

where:

MASE – the mean absolute error of the forecasting model;

Y_i, Y_{i-1} – the consecutive observed TUNINDEX20 closing values in the training sample;

n – the number of observations used to calculate the in-sample naïve scaling term.

A MASE value below 1 indicates better forecast accuracy than the naïve benchmark, whereas a value above 1 indicates inferior performance relative to the benchmark. Directional Accuracy measures the proportion of observations for which the model correctly predicts the direction of the next market movement (5):

$$\text{DA} = \frac{1}{n} \sum_{t=1}^n 1 [\text{sgn}(Y_t - Y_{t-1}) = \text{sgn}(\hat{Y}_t - Y_{t-1})] \quad (5)$$

where:

Y_t – the observed closing value at time t ;

Y_{t-1} – the observed closing value in the preceding trading session;

$\hat{Y}_t$ – the forecast closing value at time t ;

$\text{sgn}(\cdot)$ – the sign function;

Residual autocorrelation was assessed using the Ljung–Box test. Differences in forecast accuracy between competing models were evaluated using the Diebold–Mariano test. Directional forecasting performance was additionally assessed using a one-sided binomial test against a 50% random-guessing benchmark.

RESULTS

This section presents the out-of-sample forecasting results of the ANN and LSTM models and compares their performance with the naïve persistence

benchmark. The ANN model closely tracks the observed TUNINDEX20 values during the out-of-sample testing period from 2023 to 2024. Table 3

summarizes the main forecasting performance indicators obtained for the model.

Table 3. ANN model performance

No.	Metric	Value
1	MAE (Mean Absolute Error)	12.06
2	RMSE (Root Mean Squared Error)	15.92
3	MAPE (Mean Absolute Percentage Error)	0.31%
4	MASE (Mean Absolute Scaled Error)	1.0769
5	R ² (Coefficient of Determination)	0.9912
6	Directional Accuracy	53.91%
7	Gain over Random Guessing	+3.91%

Note: compiled by the authors.

The ANN model achieved an RMSE of 15.92 index points and an MAE of 12.06 index points, indicating relatively small deviations between predicted and observed index levels. The ANN model correctly predicted market direction in 53.91% of trading sessions (200 out of 371 directional movements). The average absolute error was 12.06 points, and the root-mean-square error was 15.92 points. The MAPE value of 0.31% indicates a small relative deviation of the forecasted values from the actual

ones. The high coefficient of determination confirms a close match between the forecasted and observed index values. Therefore, the results indicate a good match between the forecasted and actual index trajectories, but they do not provide grounds to claim a pronounced advantage of ANN over a simple naive forecast.

Figure 2 depicts the out-of-sample actual vs. predicted TUNINDEX20 closing prices alongside the MAE error band (± 12.06 Index Points).

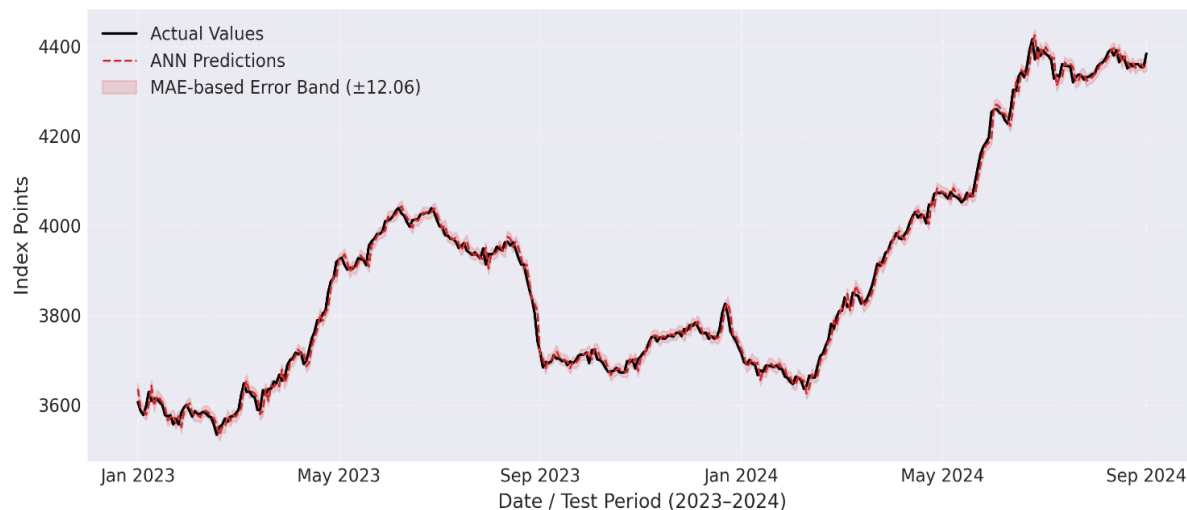


Figure 2. ANN predictions versus actual TUNINDEX20 values for 2023–2024

The predicted series displays tight alignment with actual index movements across both consolidation phases (early 2023) and strong bullish trends (mid-2024). The narrow width of the error band highlights the structural stability of the ANN architecture during changing market regimes. The predicted series closely follows the overall trajectory of the observed index. However, this visual corre-

spondence should be interpreted together with the benchmark results because of the strong persistence of the TUNINDEX20 level series.

The LSTM model also closely tracks the observed TUNINDEX20 trajectory during the out-of-sample period. Table 4 summarizes the performance metrics of the LSTM architecture.

Table 4. LSTM model performance

No.	Metric	Value
1	MAE (Mean Absolute Error)	12.23
2	RMSE (Root Mean Squared Error)	16.31
3	MAPE (Mean Absolute Percentage Error)	0.32%
4	MASE (Mean Absolute Scaled Error)	1.0914
5	R ² (Coefficient of Determination)	0.9895
6	Directional Accuracy	51.20%
7	Gain over Random Guessing	+1.20%

Note: compiled by the authors

The LSTM model achieved an MAE of 12.23 index points, an RMSE of 16.31, and a MAPE of 0.32%. These results indicate close tracking of the observed index values, although the model performs slightly less favorably than the ANN. The MASE value of 1.0914 also shows that the LSTM model did not outperform the naïve persistence benchmark in terms of scaled forecast accuracy. The model achieved a directional accuracy of 51.20%, representing a gain of only 1.20 percentage points over random guessing. Unlike the ANN, this im-

provement was not statistically significant in the binomial directional test ($p > 0.10$). In addition, the Ljung–Box test at lag 10 yielded $Q = 36.10$ with $p = 0.0001$, indicating statistically significant residual autocorrelation. This suggests that some temporal dependence remained unexplained by the LSTM model.

Figure 3 presents the visual comparison between the values predicted by the LSTM model and the actual observations from the out-of-sample test dataset.

**Figure 3.** Actual and predicted TUNINDEX20 values using the LSTM model for 2023–2024

The predicted series follows the general trajectory of the observed index, although deviations become more apparent around some turning points. The shaded area represents the uncertainty band based on the model's MAE (± 12.23 index points). The two curves display a broadly similar evolution, characterized by a satisfactory degree of overlap throughout the testing period. Most empirical ob-

servations remain within the error band, confirming that the LSTM architecture successfully reproduces the long-term upward trend. However, minor systematic lags near sharp market turning points visually illustrate the residual persistence identified by the diagnostic tests.

A direct comparison of the three forecasting approaches is presented in Table 5.

Table 5. Comparative forecasting performance

Model	RMSE	MAE	MAPE (%)	MASE
Naïve persistence benchmark	15.82	11.76	0.30	1.0000
ANN	15.92	12.06	0.31	1.0769
LSTM	16.31	12.23	0.32	1.0914

Note: compiled by the authors

The comparative results show that the ANN model performs slightly better than the LSTM model across the principal level-forecast error measures. However, the naïve persistence benchmark achieves the lowest RMSE, MAE, and MAPE values. Therefore, neither neural network model demonstrates su-

perior level-forecast accuracy relative to the naïve benchmark. Formal statistical tests provide further evidence on the differences between the models. Table 6 summarizes the main diagnostic and predictive accuracy tests.

Table 6. Summary of statistical and diagnostic tests

Statistical test	Comparison / Model	p-value	Interpretation
Ljung–Box test (lag = 10)	ANN	0.0787	No significant residual autocorrelation at the 5% level
Ljung–Box test (lag = 10)	LSTM	0.0001	Significant residual autocorrelation
Diebold–Mariano test	ANN vs. LSTM	0.2060	Difference in forecast accuracy is not statistically significant
Diebold–Mariano test	ANN vs. Naïve benchmark	0.7285	ANN does not significantly outperform the naïve benchmark
One-sided binomial test	ANN directional accuracy (200/371)	0.0730	Marginal evidence of directional predictability at the 10% level

Note: compiled by the authors

The Diebold–Mariano test indicates that the difference in forecasting accuracy between the ANN and LSTM models is not statistically significant ($p = 0.2060$). Similarly, the comparison between the ANN and the naïve persistence benchmark yields $p = 0.7285$, providing no evidence that the ANN significantly improves level-forecast accuracy relative to the benchmark.

Directional forecasting provides a somewhat different result. The ANN correctly predicts 200 out of 371 market movements, corresponding to 53.91% directional accuracy. The one-sided binomial test yields $p = 0.0730$, indicating marginal evidence that directional accuracy exceeds the 50% random-guessing benchmark at the 10% significance level. This result should nevertheless be interpreted cautiously because it does not meet the conventional 5% significance threshold.

DISCUSSION

This study provides the first comparative empirical analysis between ANN, LSTM architectures, and a non-parametric Naïve Persistence benchmark for

forecasting the TUNINDEX20, the benchmark index of the Tunis Stock Exchange. Three major findings emerge from empirical investigation. First, both neural network models closely track the observed index trajectory, reflecting the strong persistence of the TUNINDEX20 level series. Second, the ANN model performs slightly better than the LSTM model across the main point-forecasting metrics. Third, neither neural network demonstrates a statistically significant improvement in level forecasting relative to the naïve persistence benchmark.

The ANN model produced slightly lower forecasting errors than the LSTM model, with lower MAE, RMSE, MAPE, and MASE values. This suggests that greater architectural complexity did not translate into improved predictive performance for the present dataset. One possible explanation is that the available sample may be insufficient to fully exploit the more complex recurrent structure of the LSTM model. Deep neural architectures generally require relatively large datasets to achieve stable generalization and may be more sensitive to model specification and parameter tuning (Goodfellow et al., 2016).

The ANN architecture demonstrates that a drop-

out rate of 0.2 is sufficient to prevent overfitting while preserving strong predictive capability. By contrast, despite the implementation of a higher dropout rate (0.3), the LSTM model continues to exhibit systematic positive bias (+12.45 index points) and significant residual autocorrelation ($Q=36.10, p=0.0001$). This suggests that, for the present dataset, the gating mechanisms embedded within the LSTM architecture may be excessively complex, leading the model to learn market noise rather than the underlying signal (Srivastava et al., 2014).

The residuals generated by the LSTM model exhibit significant autocorrelation, whereas those produced by the ANN architecture behave similarly to white noise ($Q=16.81, p=0.0787$). Rather than reflecting a simple model deficiency, this result constitutes an empirical observation regarding the structural characteristics of the Tunisian stock market.

According to the weak-form Efficient Market Hypothesis (Fama, 1970), future returns should not be predictable using past price information. However, while Diebold–Mariano tests demonstrate that point-level forecasts do not significantly surpass naïve random-walk persistence ($p=0.7285$), the statistically significant directional accuracy achieved by the ANN model (53.91%, $p=0.0730$) and the persistence of predictable structure within LSTM residuals confirm that historical price dynamics retain exploitable non-linear patterns. These findings are consistent with previous evidence documented for emerging and frontier markets (Bekaert et al., 2017), where slower information diffusion, lower market liquidity, and stronger momentum effects are frequently observed. Consequently, the empirical findings provide additional evidence that the Tunisian market does not fully satisfy weak-form market efficiency conditions.

The findings of this study support a growing consensus in the quantitative finance literature suggesting that model complexity should be justified by the intrinsic characteristics of the data rather than by theoretical sophistication alone.

Our results are consistent with the recent findings of Kaygın et al. (2026), who show that increasing algorithmic sophistication does not necessarily translate into superior forecasting accuracy. Their conclusions emphasize the importance of algorithmic simplicity, demonstrating that less complex machine learning architectures may produce more reliable predictions. In the case of TUNINDEX20,

the superior performance and residual white-noise properties of the ANN model relative to the LSTM architecture strongly support this perspective, suggesting that predictive efficiency depends more on the adequacy of the model to the non-linear dynamics of market prices than on the architectural complexity of recurrent networks.

CONCLUSION

This study compared the forecasting performance of Artificial Neural Network (ANN) and Long Short-Term Memory (LSTM) models for the TUNINDEX20 with a naïve persistence benchmark. Using daily observations for 2012–2024, the analysis showed that both neural network models closely reproduce the general trajectory of the index, although their performance differs across forecasting and diagnostic measures.

The ANN model performed slightly better than the LSTM model in terms of MAE, RMSE, MAPE, and MASE. However, the naïve persistence benchmark produced slightly lower level-forecast errors than both neural network models. The Diebold–Mariano tests also showed that the differences in forecast accuracy were not statistically significant. These findings indicate that greater model complexity did not lead to better level forecasting for the TUNINDEX20.

Overall, the results suggest that the simpler ANN architecture is more suitable than the LSTM model for the present dataset. At the same time, neither neural network demonstrated a clear forecasting advantage over the naïve persistence benchmark. The findings therefore show that model complexity alone does not guarantee better predictive performance in a relatively persistent frontier-market index.

This study makes several contributions. First, to the best of our knowledge, it provides one of the first comparative evaluations of ANN, LSTM, and a naïve persistence benchmark for forecasting the TUNINDEX20. Second, it shows the importance of combining conventional forecast-error measures with benchmark comparisons, residual diagnostics, and directional accuracy when evaluating financial forecasting models. Third, the results provide practical evidence that simpler forecasting architectures may perform as well as, or better than, more complex recurrent models when the available data are limited and highly persistent.

Future research may extend the present analysis in several directions. First, technical indicators such as the Relative Strength Index (RSI), Moving Average Convergence Divergence (MACD), and Bollinger Bands could be incorporated into the forecasting framework to assess whether additional market information improves predictive performance. Second, macro-financial variables, including money supply, interest rates, exchange rates, foreign portfolio flows, and news sentiment, could be added to examine whether broader information improves forecasts beyond past index values alone. Third, the models could be tested across other frontier and emerging equity markets to assess the generalizability of the findings. Finally, future studies could examine adaptive and hybrid forecasting approaches, including model re-estimation under changing market conditions and reinforcement-learning-based strategies.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: YB and MS; research design: YB; data collection: YB; analysis and interpretation: YB and MS; writing draft preparation: YB and MS; supervision: MS; correction of article: YB; proofread and final approval of article: YB and MS. All authors have read and agreed to the published version of the manuscript.

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Creative New Industrialization and Economic Development of Single-Industry Towns in the Russian Far East

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ABSTRACT

The development of creative industries is considered one of the areas of structural transformation of resource-dependent and single-industry cities, whose economic development is limited by the existing sectoral specialization and spatial remoteness. The aim of the study is to identify the spatial patterns of new creative industrialization and to examine the economic factors influencing the development of creative industries in resource-oriented and single-industry cities, as well as in certain regional centers of the Russian Far East. Methods of spatial panel econometrics, global and local Moran indices, Lagrange multiplier tests, and SAR, SEM, SDM, and GSPRE models were applied. The initial data were compiled based on the financial statements of enterprises from the SPARK information and analytical system for 2013–2022. The sample includes 26 settlements (17 single-industry towns and 9 administrative centers), or 260 annual observations. The SDM_fe1 model (AIC = 913.0; BIC = 934.4) revealed positive direct effects of ICT dynamics (0.020) and the concentration of core assets in creative industries (1.131). The concentration of wages is characterized by a statistically insignificant direct effect (0.215) and a significant negative spatial effect (–2.933). The results indicate that the business climate in single-industry towns, which allows enterprises to potentially understate wages by leveraging their status as small and micro-enterprises, becomes a negative factor in spatial development, manifesting itself in a decline in the growth rates of creative industries in nearby single-industry towns.

KEYWORDS: Economy, Economic Development, Economic Diversification, Regional Economy, Spatial Development, Single-Industry Town, Russia

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Креативная новая индустриализация и экономическое развитие моногородов Дальнего Востока России

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АННОТАЦИЯ

Развитие креативных индустрий рассматривается как одно из направлений структурной трансформации ресурсозависимых и монопрофильных городов, экономическое развитие которых ограничено сложившейся отраслевой специализацией и пространственной удалённостью. Цель исследования – выявить пространственные закономерности новой креативной индустриализации и изучить экономические факторы, влияющие на развитие креативных индустрий в ресурсоориентированных и моногородах, а также в отдельных региональных центрах Дальнего Востока России. Применены методы пространственной панельной эконометрики, глобальный и локальный индексы Морана, тесты множителей Лагранжа, модели SAR, SEM, SDM и GSPRE. Исходные данные сформированы на основе финансовой отчётности предприятий информационно-аналитической системы СПАРК за 2013–2022 гг. Выборка включает 26 населённых пунктов (17 моногородов и 9 административных центров), или 260 годовых наблюдений. Модель SDM_fe1 (AIC = 913,0; BIC = 934,4) выявила положительные прямые эффекты динамики ИКТ (0.020) и концентрации основных средств креативных индустрий (1.131). Концентрация заработной платы характеризуется статистически незначимым прямым эффектом (0.215) и значимым отрицательным пространственным эффектом (–2.933). Результаты свидетельствуют о том, что деловой климат в моногородах, позволяющий предприятиям потенциально занижать заработную плату, используя свой статус малых и микропредприятий, становится негативным фактором пространственного развития, проявляясь в снижении темпов роста креативных индустрий в близлежащих моногородах.

КЛЮЧЕВЫЕ СЛОВА: экономика, экономическое развитие, экономическая диверсификация, региональная экономика, пространственное развитие, моногород, Россия

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INTRODUCTION

Resource-based and single-industry towns have attracted growing scholarly attention because structural constraints affect their economic development and diversification (He et al., 2017; Hu, 2024; Pani, 2009). From the perspective of urban development cycles and techno-economic paradigms, creating and renewing development paths in remote industrial cities remain important research challenges (Czamanski & Broitman, 2018; Perez, 2002; Wan et al., 2015). Periods of economic stagnation may encourage searches for alternative development trajectories shaped by emerging economic and technological trends (Li, 2020; Priemus, 2004). Among these trends, creative industries have received increasing attention as a potential source of regional economic transformation (Capello, 2008; Evans, 2009; Kourtit & Nijkamp, 2019; Turgel et al., 2023).

The UK Department for Culture, Media and Sport (DCMS) played an important role in establishing creative industries as a distinct area of economic activity through its mapping documents published in 1998 and 2001 (DCMS, 1998, 2001). Creative industries represent a significant component of the globaleconomy, contributing approximately 3.1% of global GDP. However, their economic contribution varies considerably across countries, ranging from 0.5% to 7.3% of GDP among the economies covered by the UNCTAD survey. Software services and research and development (R&D) have become particularly important components of creative services exports, accounting for 41.3% and 30.7%, respectively, in 2022. Digitalization is also transforming the production, distribution and consumption of creative goods and services (Li, 2020; UNCTAD, 2024).

The development of creative industries is closely associated with the formation of creative clusters, which facilitate knowledge exchange, cooperation and economic interaction among enterprises (Boal-San Miguel & Herrero-Prieto, 2020; He & Gebhardt, 2014; Porter, 1998). At the same time, digital technologies are increasingly influencing the development patterns of these clusters (Li, 2020). Several national and international classifications of creative industries include software and related digital activities, although their scopes differ. In this study, information and communication

technologies (ICT) are examined separately from other creative industries to assess their potential role as the technological core of creative new industrialization. Particular attention is given to geographically isolated resource-based settlements, where established industrial structures and limited transport accessibility may constrain the emergence of new economic activities.

This study aims to identify spatial patterns of creative new industrialization and examine the economic factors influencing the development of creative industries in resource-based and single-industry towns and selected regional centers of the Russian Far East. The research hypothesis suggests that the growth of information and communication activities is positively associated with the development of non-ICT creative industries, even under conditions of path dependence and spatial interdependence shaped by road accessibility.

To test this hypothesis, the study applies spatial econometric models to panel data covering 26 settlements from 2013–2022. The analysis examines the relationship between ICT growth and the dynamics of non-ICT creative industries, accounting for fixed-asset concentration, wage concentration, and spatial interactions between settlements.

The remainder of the article is structured as follows. The literature review examines the theoretical foundations of creative new industrialization and path renewal. The methodology section describes the data sources, variables, and spatial econometric approach. The results section presents the estimated relationships and spatial effects, followed by a discussion of their implications for regional economic development. The conclusion summarizes the study's main findings and limitations.

LITERATURE REVIEW

According to Porter (1998), clusters represent geographic concentrations of interconnected firms and institutions that benefit from proximity, knowledge exchange, and competitive advantages. The cluster approach emphasizes the importance of geographical concentration in shaping regional economic development. Nevertheless, Porter's cluster theory has been widely criticized for its conceptual ambiguity, methodological limitations,

and challenges in practical implementation (Swords, 2013). The new industrial approach, based on the techno-economic paradigm and developed in Perez's work, assumes the dominant role of the technological factor in economic development. The modern stage belongs to the era of information and communication technologies, whose introduction is becoming a key driver of economic development (Madalin & Andreica, 2023; Perez, 2002). However, this approach does not explicitly account for local conditions and, therefore, does not fully explain the development challenges faced by remote resource-based cities characterized by established industrial structures (Glazyev, 2009).

These settlements operate within a complex system of technological interactions, in which technologies associated with different techno-economic paradigms exert mutual influence. Such interactions may be facilitative, inhibitory, or neutral, shaping the trajectory of technological development across economic sectors (Pilyasov & Kotov, 2024; Pistorius & Utterback, 1997). Furthermore, resource-based cities and single-industry towns are characterized by strong path dependence, where new technologies may face resistance from established institutional norms and economic structures (Hayter, 2017; Zamyatina & Pilyasov, 2016). In this context, integrating new industrial and cluster-based approaches provides a theoretical basis for examining the development of creative industries. This integration can be conceptualized through creative new industrialization and the formation of creative information and communication clusters.

Creative industries represent economic activities associated with the commercial application of intellectual property derived from individual creativity. These activities encompass art and antiques, music, architecture, media, fashion and design, film, and publishing. Software and game production have also become important components of creative industries. Educational activities and research and development (R&D) are classified separately under certain national frameworks (Antonova, 2025; DCMS, 1998, 2001; He & Gebhardt, 2014; Stam et al., 2008). Software developed within ICT activities serves as a technological foundation for a wide range of economic sectors, extending beyond creative industries (Glazyev, 2009). Although Florida

(2017) identified ICT-related employment as an important component of the creative class, digital technologies increasingly influence economic activities across different sectors (Madalin & Andreica, 2023). Consequently, ICT and related activities can be considered fundamental to the technological paradigm of new industrialization, including creative new industrialization.

Creative industries are frequently examined in relation to local identity formation through the integration of historical heritage into urban regeneration initiatives. This approach often involves introducing creative activities into historically significant urban spaces to stimulate their revitalization (Zeng et al., 2020). The creative reindustrialization of abandoned industrial sites has also become a visible manifestation of China's Second Transition, attracting international attention (Zielke & Waibel, 2014). Numerous projects worldwide integrate local historical identity (Genius Loci) with contemporary technological and cultural transformation (Zeitgeist). Examples include the Confluence project in Lyon (France), HafenCity in Hamburg (Germany), Stary Browar in Poznań (Poland), the Cultural Industries Quarter in Sheffield (UK), industrial building conversions in Forssa (Finland), the Vienna Gasometers (Austria), the DUMBO district in New York (USA), the conversion of fuel tanks into art galleries in the Longhua Airport area in Shanghai (China), the transformation of slaughterhouses into a cultural centre in Porto (Portugal), the conversion of a granary into a hotel in Cape Town (South Africa), the reconstruction of a former fire station in the port of Antwerp (Belgium), and the GES-2 House of Culture in Moscow (Russia). These examples illustrate the potential of creative industries, particularly in architecture and urban regeneration, to incorporate cultural heritage into contemporary spatial development.

Although the physical transformation of cities is not always immediately visible, redevelopment, revitalization and reindustrialization may generate significant economic effects. The emergence of a digital creative cluster in East London following the 2008 financial crisis illustrates the role of geographical concentration and interaction between digital technologies, advertising, design, marketing and communications (Foord, 2013). Such interactions between different creative activities

contribute to the emergence of new products and business models, although their development patterns remain heterogeneous. In this context, information and communication activities may provide a technological foundation for creative new industrialization and contribute to the renewal of established urban development paths (Antonova, 2025; Li, 2020; Zamyatina & Pilyasov, 2016).

A scientometric analysis of publications indexed in the Lens database was conducted to examine research patterns associated with techno-economic and cluster paradigms, both as independent theoretical approaches and in relation to creative industries. Figure 1 presents the keyword co-occurrence network for publications examining the techno-economic paradigm.

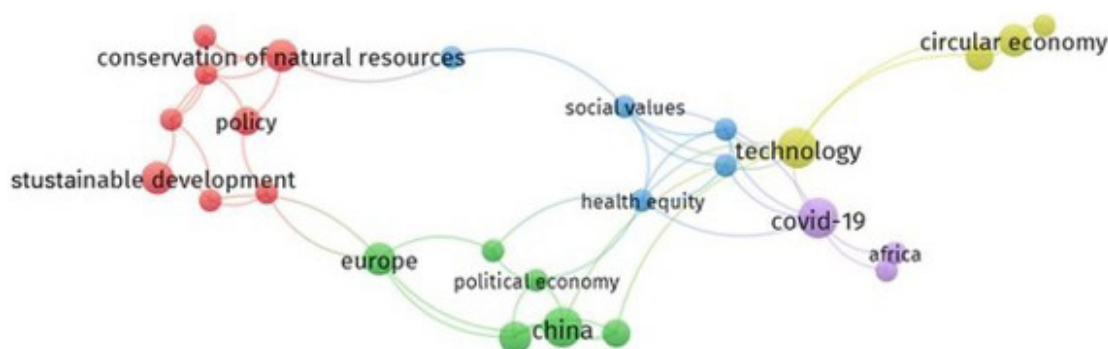


Figure 1. Keyword co-occurrence network for the techno-economic paradigm

Figure 1 shows that research on the techno-economic paradigm covers several interconnected areas. Technology occupies a central position in the network, linking social values and health equity with COVID-19 and the circular economy. A separate thematic cluster brings together sustainable development, natural resource conservation and policy, while China, Europe and political economy form another group of related keywords. These

connections indicate that researchers increasingly examine technological change alongside the environmental, social, and institutional aspects of economic development.

To examine the application of cluster theory within creative industries, we constructed a corresponding keyword co-occurrence network (Figure 2).

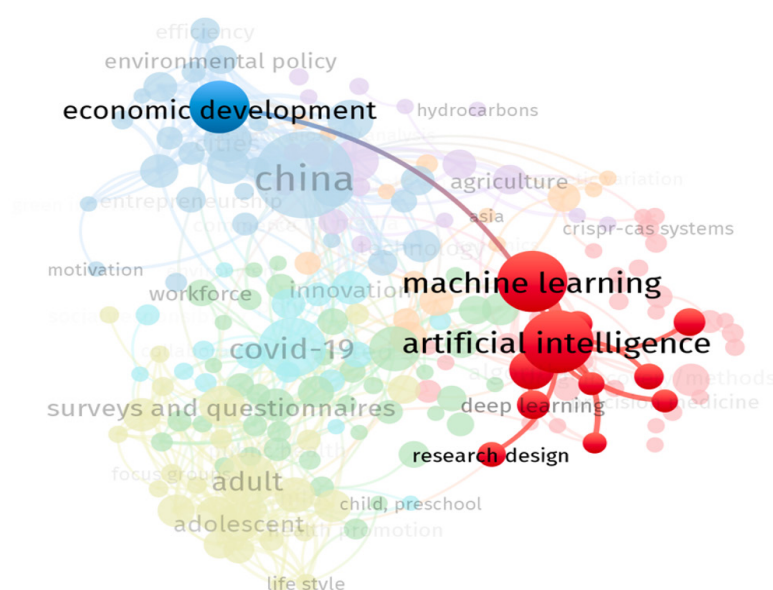


Figure 2. Keyword co-occurrence network for the cluster paradigm in creative industries

Figure 2 highlights the growing role of artificial intelligence and machine learning, which form a distinct and closely connected cluster. Another prominent group brings together China, economic development, innovation and COVID-19, reflecting the relationship between technological change and broader economic processes. A separate

cluster includes surveys and questionnaires, adult, adolescent and lifestyle-related research. The links between these groups indicate that studies within the cluster paradigm increasingly combine digital technologies, economic development and social dimensions.

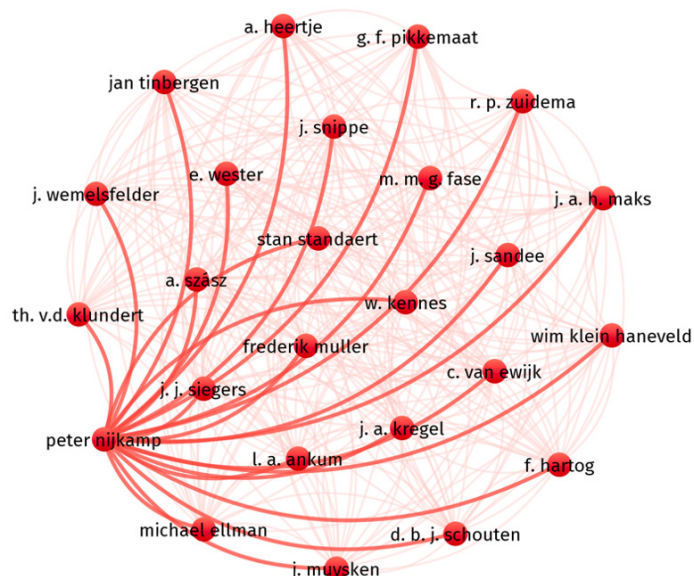


Figure 3. Co-authorship network for research on the techno-economic paradigm in creative industries

Figure 3 shows a dense network of scientific collaboration, with Peter Nijkamp occupying a prominent position through numerous connections with other researchers. Particularly strong links are observed between Nijkamp and several authors, including J. J. Siegers, F. Müller and J. A. Kregel. The network also includes Jan Tinbergen, A. Heertje, G. F. Pikkemaat and other scholars. The concentration of connections around Nijkamp highlights his role in the collaborative research network associated with the techno-economic paradigm.

The co-authorship network illustrates collaboration patterns within this research area. P. Nijkamp's contribution is particularly relevant to the conceptual development of creative knowledge cities (Van Geenhuizen & Nijkamp, 2012). The edited volume *Creative Knowledge Cities: Myths, Visions and Realities* examines the relationship between knowledge, creativity and urban development. Nevertheless, existing research places considerable emphasis on knowledge-based urban transformation, while the potential of

creative industries to facilitate structural economic change in remote industrial settlements remains insufficiently explored.

Remote resource-based cities and single-industry towns face considerable challenges in creating new development paths. In such settlements, developing creative industries may offer opportunities to overcome established economic structures and support path renewal. ICT can play an important role in this transition by providing a technological basis for creative new industrialization (Antonova, 2025). However, strong path dependence, associated with established institutional norms and economic structures, may constrain the adoption of new technologies. This is particularly relevant to single-industry towns, where economic development has historically been shaped by the interests and activities of a dominant, often resource-based enterprise (Martin, 2017).

New path creation involves both the emergence of new economic activities and the restructuring of existing town-forming industries. Small and

medium-sized enterprises can contribute to this process, particularly when supported by appropriate business infrastructure (Muraya, 2006). Special economic zones (SEZs) represent one possible instrument for stimulating industrial diversification and attracting new enterprises, although their effectiveness in promoting industrial growth and technological development varies across regions (Ye et al., 2024).

Combining the theory of technological paradigm shifts with Porter's cluster approach provides a framework for examining the development of creative industries in geographically isolated settlements of the Russian Far East (Glazyev, 2009; Perez, 2002). While Perez emphasizes the role of ICT in the current techno-economic paradigm, Porter's approach highlights the importance of geographical concentration, inter-firm relationships, and local economic conditions.

Within this framework, path dependence is operationalized through wage concentration, which reflects the distribution of reported wage payments among enterprises within a town. A high concentration may indicate the continued dominance of a limited number of employers, particularly town-forming enterprises, whereas lower concentration may reflect a more diversified local business structure. Although this indicator does not directly measure institutional quality or informal economic activity, it provides an opportunity to examine the relationship between established economic structures and the development of creative industries.

Thus, combining cluster theory with the techno-economic approach provides a theoretical basis for examining creative new industrialization in remote resource-based and single-industry towns. Particular attention is given to the role of ICT, established industrial structures and geographical accessibility in shaping the development of creative industries and the potential for path renewal.

RESEARCH METHODS

The study examines the relationship between information and communication technologies (ICT) and the development of creative industries in resource-based and single-industry towns of the Russian Far East. The empirical approach draws on the cyclical interpretation of regional

economic development and considers the potential bidirectional relationship between creative industries and local economic conditions (Capello & Nijkamp, 2009; Aoyama et al., 2015; Czamanski & Broitman, 2018). The analysis examines the relationship between creative industry dynamics and selected explanatory factors and introduces predetermined lags for concentration measures to reduce potential contemporaneous feedback (Czamanski & Broitman, 2018; Kitchin, 1923; Kuznets, 1940; Markusen, 1985). Given the relatively early stage of creative new industrialization in Russia, the study specifies the dynamics of non-ICT creative industries as the dependent variable (Antonova, 2025; Gushchina & Tarabanova, 2022). The study examines ICT development, enterprise concentration, and spatial accessibility as explanatory factors. Temporal relationships between the main variables are additionally assessed using panel fixed-effects Granger-style tests.

The dependent variable (CIGR) measures change in the aggregated revenue of creative industries, excluding ICT activities. The corresponding ICT indicator (ITGR) is calculated separately to examine the relationship between digital activities and the development of other creative sectors. Both indicators are expressed as annual revenue growth factors (1):

$$CI_{GR} = \frac{CI_t}{CI_{t-1}} \quad (1)$$

where:

CI_{GR} – the annual revenue growth factor of creative industries excluding ICT in settlement i in year t ;

CI_t – the aggregate revenue of non-ICT creative industries and ICT enterprises;

i, t – settlement identifier.

The independent variable reflecting the co-development of creative industries with ICT will be the dynamics of aggregated ICT revenue, calculated using the formula (2):

$$IT_{GR} = \frac{IT_t}{IT_{t-1}} \quad (2)$$

where:

IT_t – the annual aggregated revenue of ICT enterprises, adjusted for the rate of inflation, t – year.

A factor greater than 1 indicates revenue growth, while a factor between 0 and 1 indicates a decline. A zero denominator makes the respective ratio undefined; the treatment of such cases must be specified consistently with the estimation dataset. Structural path dependence is proxied by the Herfindahl–Hirschman Index of reported wage concentration across all enterprises within a settlement, calculated using the formula (3):

$$HHIW_{it} = \sum_{k=1}^{m_{it}} \left(\frac{W_{kit}}{W_{total,it}} \right)^2 \quad (3)$$

where:

$HHIW_{it}$ – Herfindahl–Hirschman Index of wage concentration in settlement i in year t ;

W_{kit} – the annual reported wage bill of enterprise k in settlement i in year t ;

$W_{total,it}$ – the sum of the reported wage bills of all enterprises included for settlement i in year t ;

m_{it} – the number of enterprises included in the wage-concentration calculation.

A higher $HHIW$ value indicates a greater concentration of reported wage payments among a limited number of enterprises, reflecting the potential dominance of town-forming employers. In this study, wage concentration is used as an indicator of structural path dependence rather than a direct measure of institutional quality or informal economic activity. The dominance of a single town-forming enterprise ($HHI_W=1$) results in the formal reporting of wage income primarily by that enterprise. Consequently, other enterprises, including those in the creative industries, may exhibit lower levels of formal economic activity, potentially reflecting engagement in the informal sector or alternative reporting practices.

The concentration of fixed assets in creative industries (HHI_{CIFA}) as independent variable is calculated as follows (4):

$$HHICIFA_{it} = \sum_{k=1}^{q_{it}} \left(\frac{FA_{kit}}{FA_{total,it}} \right)^2 \quad (4)$$

where:

$HHICIFA_{it}$ – Herfindahl–Hirschman Index of fixed-asset concentration among creative-industry enterprises in settlement i in year t ;

FA_{kit} – the value of fixed assets held by creative-industry enterprise k in settlement i in year t ;

$FA_{total,it}$ – the sum of fixed assets of all creative-industry enterprises included for settlement i in year t ;

q, it – the number of creative-industry enterprises included in the calculation

Both concentration measures range from 0 to 1 when defined using non-negative enterprise values. Higher values indicate a more concentrated distribution; the precise lower bound depends on the number of enterprises. Previous research suggests that creative industries in Russian single-industry towns may mirror the concentrated structure of local economies (Antonova & Pchelintsev, 2023).

Predetermined concentration variables were constructed from an extended SPARK dataset covering 2010–2022. In the baseline estimation, $HHICIFA$ enters with a one-year lag ($t-1$), and $HHIW$ enters with a three-year lag ($t-3$). Alternative wage-concentration lags ($t-1$, $t-2$, and $t-3$), with $HHICIFA$ held at $t-1$, were compared using the Akaike, Bayesian, and Hannan–Quinn information criteria. The lagged variables are matched to all 260 observations in the final estimation sample. Complementary panel fixed-effects Granger-style tests examine the main variables at lag orders 1–3.

To consider the spatial factor of transport accessibility, the matrix of inverse distances between the cities of the Far Eastern Federal District by road are gathered, sorted and explored W_{ij} (5):

$$W_{ij} = \begin{cases} 0, & \text{if } i = j, \\ \frac{1}{d_{ij}}, & \text{if } i \neq j, \end{cases} \quad (5)$$

where:

W_{ij} – row-standardized spatial weight linking settlement i to settlement j ;

d_{ij} – road distance between settlements i and j ;

i, j – indices of settlements;

k – index used to sum inverse distances across settlements.

The diagonal elements are set to zero, and the spatial weight matrix is row-standardized so that

the sum of weights in each row equals one. The same matrix is used for spatial autocorrelation diagnostics and spatial regression estimation.

Spatial autocorrelation is assessed using global Moran's I and local Moran's I (LISA). Lagrange-multiplier and robust LM diagnostics are used to examine spatial dependence. Conventional fixed-and-random-effects specifications are compared with spatial autoregressive (SAR), spatial error (SEM), Spatial Durbin (SDM) and generalized spatial panel random-effects (GSPRE) specifications where applicable. Model selection considers information criteria and spatial diagnostics; the reported focal specification is SDM_fe1.

The introduction of the distance matrix makes it possible to estimate the spatial autocorrelation indices – the global (I) and local (LISA) Moran indices (Pregi & Novotný, 2025) using the following formulas (6-7):

$$I = \frac{n}{K} \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (6)$$

$$Lisa = \frac{n(x_i - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2} \sum_{j=1}^n W_{ij} (x_j - \bar{x}) \quad (7)$$

where:

x_i, x_j – the attribute features of objects i and j , respectively;

$\bar{x}$ – the average value of the feature for n objects;

W_{ij} – the spatial weight for a pair of objects i and j ;

n – the total number of objects, K is the sum of the weights.

The Local Moran's I values are considered only for those year windows where the index was statistically significant at the $p < 0.05$ level. Years with non-significant spatial autocorrelation were excluded to avoid cluttering the analysis with noise. The Lagrange test also confirms the evaluation results. Significant LM-lag and Robust LM-lag indicate a spatial lag of the dependent variable, robust to spatial autocorrelation in errors. The presence of spatial autocorrelation will indicate the presence of spatial effects in the variables of the regression model, which in the general case will be presented as follows (8):

$$y_{it} = \alpha + \beta_k x_{kit} + \varepsilon_{it} \quad (8)$$

where:

y_{it} – dependent variable;

x_{kit} – group of independent variables;

ε_{it} – the remnants of the model.

The model allows for testing fixed and random effects of time and place. Next, the following spatial regression models are tested (9–13).

1. The spatial autoregressive model (SAR), estimated to have fixed effects (SAR_fe) and random effects (SAR_re), is expressed as follows (9):

$$y_{it} = \alpha + \beta_k x_{kit} + \rho W y_{it} + \mu_i + \varepsilon_{it}, \quad (9)$$

2. The spatial error model (SEM), estimated to have fixed effects (SEM_fe) and random effects (SEM_re), is specified as follows (10):

$$y_{it} = \alpha + \beta_k x_{kit} + \mu_i + \lambda W u_{it} + \varepsilon_{it}, \quad (10)$$

3. The spatial autoregressive combined model (SAC), incorporating both spatial lag and spatial error dependence, is specified as follows (11):

$$y_{it} = \alpha + \rho W y_{it} + \beta_k x_{kit} + \mu_i + \lambda W u_{it} + \varepsilon_{it} \quad (11)$$

4. The Spatial Durbin model (SDM), estimated with fixed effects (SDM_fe) and random effects (SDM_re), is expressed as follows (12):

$$y_{it} = \alpha + \rho W y_{it} + \beta_k x_{kit} + \theta W x_{it} + \mu_i + \varepsilon_{it} \quad (12)$$

5. The generalized spatial panel random-effects model (GSPRE) is represented by the following specification (13):

$$y_{it} = \rho W y_{it} + \alpha + \beta_k x_{kit} + \theta W x_{it} + \mu_i + \lambda W u_{it} + \varepsilon_{it} \quad (13)$$

where:

y_{it} – the dependent variable for town i at time t ;

x_{kit} – the independent variable for town i at time t ;

β_k – coefficients for independent variables;

α – the free term;

μ_i – individual effects of cities (fixed or random);

ε_i – residuals (random errors);

$\rho W y_{it}$ – the spatial lag of the dependent variable y_{it} ;

$\lambda W u_{it}$ – the spatial lag of the residuals in the model;

$\theta W x_{it}$ – the spatial lag of the independent variable x_{it} .

The focal empirical specification is the panel Spatial Durbin model with entity fixed effects (SDM_{fe1}), including spatial lags of CIGR and HHIwT alongside ITGR, HHIciFA and the predetermined concentration lags. SAR, SEM, SAC, alternative SDM specifications, pooled FE/RE and GSPRE models are estimated for comparison, taking into account the results of the Lagrange multiplier tests.

DATA

Data were obtained from the SPARK information and analytical system, which provides financial

statements of registered legal entities, primarily limited liability companies. Enterprises were classified into creative industries and ICT activities using OKVED (All-Russian Classification of Economic Activities), while their territorial location was identified using OKATO (All-Russian Classification of Administrative-Territorial Entities). To test the research hypothesis, a database covering single-industry towns and administrative centres in the Far Eastern Federal District was compiled. The final dataset comprises a balanced panel of 26 settlements over the period 2013–2022 (10 years), providing 260 annual observations.

The sample includes nine administrative centres: Vladivostok, Magadan, Ulan-Ude, Khabarovsk, Chita, Yakutsk, Birobidzhan, Blagoveshchensk and Petropavlovsk-Kamchatsky; and 17 single-industry towns: Arsenyev, Artem, Belogorsk, Dalnegorsk, Krasnokamensk, Lipovtsy, Luchegorsk, Mirny, Neryungri, Pevek, Raichikhinsk, Svetlogorye, Svobodny, Severobaikalsk, Spassk-Dalny, Tynda and Yaroslavsky. Figure 4 presents the spatial distribution of the selected settlements and creative-industry dynamics in 2022.

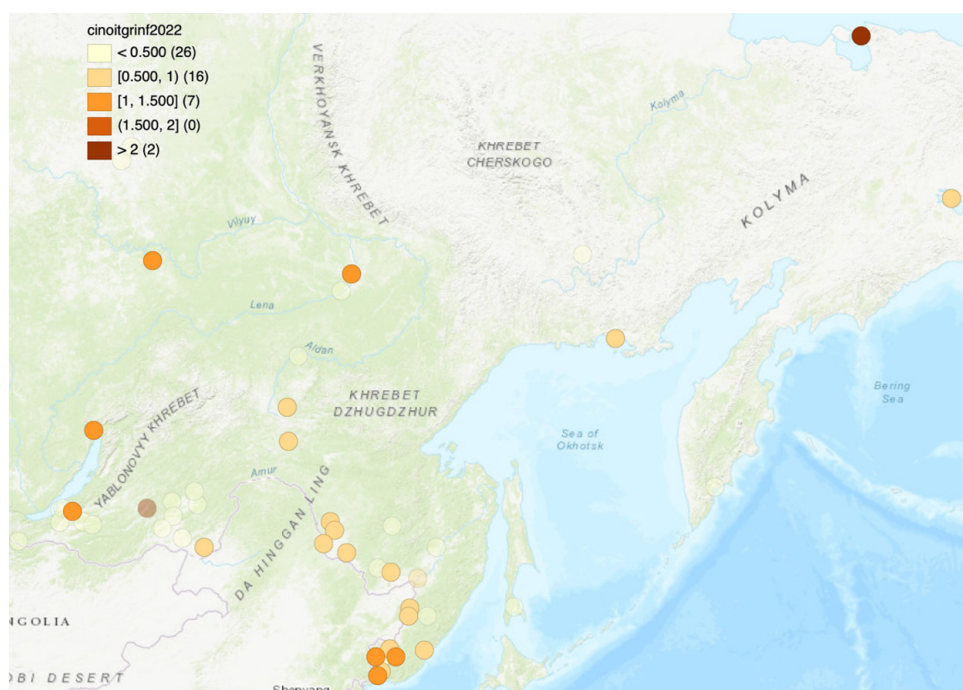


Figure 4. Spatial distribution of creative-industry dynamics in resource-based and single-industry towns and administrative centres of the Russian Far East in 2022

Visual analysis of descriptive statistics shows that the dynamics of revenue in the creative

industries, adjusted for the rate of inflation, are generally evenly distributed. The concentration of

creative industries in single-industry and resource-based towns in the Far Eastern Federal District is associated with the established settlement system

mainly in the southern part of the microregion, in Primorsky Krai. A list of single-industry cities is presented in Table 1.

Table 1. Resource-based and single-industry towns of the Russian Far East included in the study for 2013–2022

No.	Town / Settlement	Region	Main economic activity
1	Arseniev	Primorsky Krai	Aerospace, mechanical engineering
2	Artem	Primorsky Krai	Thermal power engineering
3	Belogorsk	Amurskaya oblast	railway
4	Dalnegorsk	Primorsky Krai	mining
5	Krasnokamensk	Zabaikalsky Krai	uranium mining
6	Lipovtsi	Primorsky Krai	Coal mining
7	Luchegorsk	Primorsky Krai	Thermal power engineering
8	Mirniy	Respublika Saha (Yakutiya)	Diamond mining
9	Nerungri	Respublika Saha (Yakutiya)	Coal mining
10	Pevek	Chukitsky Avtonomny Okrug	Seaport
11	Raichihinsk	Amursk oblast	Coal mining
12	Svjatogorie	Primorsky Krai	Extraction and processing of tungsten ore
13	Svobodniy	Amurskaya oblast	Railway, gas transportation
14	Severobaikalsk	Respublika Burjatia	Railway
15	Spassk-Dalniy	Primorsky Krai	Mining, processing, and cement production
16	Tynda	Amurskaya oblast	Railway, mining
17	Yaroslavskiy	Primorsky Krai	Coal mining

Note: compiled by the authors

Table 1 presents 17 single-industry and resource-dependent settlements in the Russian Far East included in the study. The largest number of them are located in Primorsky Krai (8). The local economy is primarily based on the extractive industry, energy, mechanical engineering, and railway transport. Differences in sectoral specialization make it possible to examine the development of creative industries in cities with different structures of traditional economic activity.

Information and communication activities also

demonstrate positive average dynamics, although ITGR exhibits substantially greater variation across settlements and years. Previous research suggests that creative industries in single-industry towns of the Urals and Siberia tend to reproduce the concentrated structure of local economies rather than develop through diversification (Antonova, 2025; Antonova & Pchelintsev, 2023). The dynamics of information and communication activities are growing (Table 2).

Table 2. Data descriptive statistics

Variable	Variation	Mean	Std. dev.	Min	Max	Sample size
CI _{GR}	overall	1.252939	1.534527	0	18.12744	260
	between		.4318643	.6072397	2.6868	26
	within		1.474702	-1.25103	16.69358	10
IT _{GR}	overall	1.111879	9.329303	0	150.4818	260
	between		3.098206	0	16.07848	26
	within		8.818762	-14.10617	135.5152	10
HHI _{CI-FA} (t-1)	overall	.4845704	.3726349	0	1	260
	between		.3176781	0	1	26
	within		.2035787	-.4062058	1.38457	10
HHI _w (t-3)	overall	.2718117	.2887948	0	1	260
	between		.1954764	.02627	.7669514	26
	within		.2156831	-.4951398	.9767382	10

Note: compiled by the authors

In this case, the concentration of fixed assets in creative industries is considered a factor in their growth, with an average level of 0.48, a maximum of 1, and a minimum of 0. The concentration of wages, with an average level of 0.27, indicates that, in general, small and medium-sized businesses are developing in single-industry and resource-rich cities of the Far East, reflecting wages in reporting.

RESULTS

At the first stage, a comparative assessment of panel regression models was carried out, considering the spatial dependence between the cities under study. Based on the comparison results, the spatial Durbin model with fixed effects (SDM_{fe1}) yielded the lowest AIC (913.0) and BIC (934.4) values. This model was used for further analysis of the factors influencing the development of creative industries and for assessing spatial effects. Appendix 1 presents the detailed regression results.

Panel fixed-effects Granger-style tests of temporal precedence are reported for the core variables, with primary focus on the relationship between IT_{GR} and CI_{GR} . For lag orders 1 and 2, the null that lagged IT_{GR} does not predict CI_{GR} is rejected at the 10% level ($p \approx 0.08$ for order 1; joint test $p \approx 0.07$ for orders 1–2). The reverse specification, from lagged CI_{GR} to IT_{GR} , does not yield a significant result ($p \approx 0.14$ for order 1). Predetermined lags of HHI_{CIFA} and HHI_W are constructed from the extended SPARK panel beginning in 2010; sensitivity to alternative wage-concentration lags of order $t-1$, $t-2$ and $t-3$ (with HHI_{CIFA} held at $t-1$) indicates selection of the $t-3$ specification by AIC, BIC and the Hannan–Quinn criterion. Auxiliary FE robustness checks for skewed growth ratios leave the signs of HHI_{CIFA} and HHI_W unchanged under 1%/99% winsorization; the IT_{GR} coefficient is more sensitive to the extreme Ulan-Ude 2013 observation.

The analysis revealed statistically significant positive coefficients for the concentration of fixed assets in the creative industries (HHI_{CIFA}) and the growth rate of information technology (IT_{GR}). However, the impact of information technology was substantially weaker compared to the effects of path

dependency. Path dependency, reflected in the self-similar nature of the creative industries' system, manifests through the spatial concentration of fixed assets (HHI_{CIFA}) and wages (HHI_W). Evidence for this spatial pattern is provided by statistically significant variables in the SDM_{fe1} model, as well as a significant global Moran's.

The local Moran's I index was estimated to identify spatial growth poles within the creative industries. The analysis focused on statistically significant high values of the local Moran's I index, surrounded by high and low values. In resource-based and single-industry towns in the Far East, factors influencing creative-industry development show spatial heterogeneity, while the dynamics of these industries tend to be spatially homogeneous. The ICT growth points in the space of resource-based and single-industry cities of the Far East are formed in the regional centers of Ulan-Ude ($Lisa_{2017} = Lisa_{2018} = 0.341$) and Chita ($Lisa_{2017} = 0.244$ and $Lisa_{2018} = 0.252$), as well as in Krasnokamensk ($Lisa_{2017} = 0.166$ and $Lisa_{2018} = 0.114$) (Zabaikalsky Krai) and Severobaikalsk ($Lisa_{2017} = 0.099$ and $Lisa_{2018} = 0.113$) (Republic of Buryatia). These observations are predominantly in the first quadrant of the Moran scatter plot, indicating high-high spatial autocorrelation, with high values clustered among similarly high values of the parameter under consideration. A high level of concentration of fixed assets in creative industries is observed in Luchegorsk ($Lisa_{2016} = 0.480$ and $Lisa_{2017} = 0.378$, I quadrant of the scattering matrix), Svetlogorye ($Lisa_{2017} = 0.380$, I quadrant of the scattering matrix) and Spassk-Dalniy ($Lisa_{2016} = -0.493$ and $Lisa_{2017} = -0.602$, IV quadrant of the scattering matrix) (Primorsky Krai). The concentration of wages across the town has a high value, surrounded by high or low values of resource-based and single-industry cities in Dalnegorsk ($Lisa_{2019} = 0.208$), Luchegorsk ($Lisa_{2019} = 1.236$), Svetlogorye ($Lisa_{2019} = 1.225$) (Primorsky Krai) and Severobaykalsk ($Lisa_{2019} = -0.187$) (Republic of Buryatia).

Table 3 presents the assessment of spatial indirect effects (spillover effects) within the studied area of the Far East.

Table 4. Spatial effects of the models

Effect	Variable	sar_fe	sar_re	sdm_re	sdm_fe	sdm_re1	sdm_fe1
Direct	IT _{GR}	0.023**	0.023**	0.018*	0.019*	0.021**	0.020**
		(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
	HHI _{ciFA}	1.221***	0.677***	0.622***	1.089***	0.635***	1.131***
		(0.417)	(0.238)	(0.234)	(0.418)	(0.233)	(0.409)
	HHI _{WT}	-0.397	-0.519*	-0.214	0.197	-0.194	0.215
		(0.404)	(0.312)	(0.325)	(0.448)	(0.324)	(0.445)
Indirect	IT _{GR}	0.015	0.014	-0.075	-0.045	0.006	0.007
		(0.010)	(0.009)	(0.084)	(0.089)	(0.006)	(0.007)
	HHI _{ciFA}	0.825	0.397	0.319	0.304	0.165	0.389
		(0.543)	(0.246)	(1.312)	(1.838)	(0.167)	(0.349)
	HHI _{WT}	-0.220	-0.288	-3.108***	-3.133***	-2.797***	-2.933***
		(0.285)	(0.221)	(0.952)	(1.050)	(0.793)	(0.851)
Total	IT _{GR}	0.038**	0.037**	-0.056	-0.026	0.026*	0.027*
		(0.018)	(0.018)	(0.088)	(0.092)	(0.014)	(0.014)
	HHI _{ciFA}	2.047**	1.074**	0.942	1.393	0.800**	1.520**
		(0.851)	(0.431)	(1.320)	(1.934)	(0.329)	(0.654)
	HHI _{WT}	-0.617	-0.807	-3.322***	-2.936***	-2.991***	-2.719***
		(0.659)	(0.498)	(0.947)	(1.063)	(0.771)	(0.820)

Note: compiled by the authors

The spatial econometric models, based on a matrix of inverse distances between resource-based and single-industry towns by road, showed the so-called indirect effect of wage concentration on the dynamics (its decrease) of creative industries in nearby resource-based and single-industry towns. The observed high-wage concentration is characteristic of resource-based and single-industry towns, where wage data is predominantly reported by large, town-forming enterprises. This study demonstrates the ability to assess the spatial influence of institutional factors, specifically the entrepreneurial climate, on creative industries. Results indicate that in resource-based and single-industry towns where a town-forming enterprise predominantly reports wage data, a negative spatial spillover effect is observed, leading to reduced creative industry dynamics in closely located neighboring towns. However, within the town itself, this effect is not observed; instead, wage concentration generally enhances creative-industry dynamics. A convergence of creative industries is observed in resource-based and single-industry towns where the business climate enables these industries to potentially underreport wages by leveraging their status as small and micro businesses. This facilitates spatial dependence as inertia of the prevailing technological order. The statistically indistinguishable-from-zero direct effect suggests

that internal transparency alone cannot overcome the structural lock-in of a legacy mono-town. Conversely, the significant indirect effect captures the cross-border diffusion of uncertainty generated by neighboring legacy systems.

DISCUSSION

The findings contribute to the literature on regional economic development by examining the role of creative industries in the renewal of established development paths in remote resource-based and single-industry towns of the Russian Far East. Combining Porter's cluster approach with the theory of technological paradigm shifts (Porter, 1998; Perez, 2002; Pilyasov & Kotov, 2024) provides a basis for understanding the relationship between technological change and the existing industrial structure of these settlements. The results indicate that the development of creative industries is associated with both ICT growth and the concentration of fixed assets within the creative sector. This finding is consistent with earlier evidence that creative industries in single-industry towns may reproduce the concentrated economic structures characteristic of their local economies (Antonova, 2025; Antonova & Pchelintsev, 2023).

Previous studies have examined creative industries primarily in relation to urban

diversification, cultural assets and local identity (Evans, 2009; Florida, 2017; Zeng et al., 2020). The present research adds another dimension by considering the economic relationships between ICT activities and other creative industries in remote industrial settlements. The positive coefficient of ITGR indicates that ICT revenue growth is associated with the development of non-ICT creative industries. At the same time, the positive relationship between fixed-asset concentration and creative-industry growth suggests that the development of these activities does not necessarily follow a diversification pattern. This finding is particularly relevant to single-industry towns, where established economic specialization continues to influence the emergence of new activities.

An important result concerns the spatial effect of wage concentration. While its direct effect within individual settlements is statistically insignificant, the negative indirect effect indicates that higher wage concentration is associated with slower creative-industry growth in neighbouring settlements. This relationship may reflect the persistence of established economic structures across geographically connected towns. However, wage concentration should not be interpreted as direct evidence of institutional weakness or informal business practices, since these characteristics were not measured separately in the study.

The distinction between ICT and other creative industries also contributes to the discussion of creative new industrialization. Existing classifications commonly include digital activities within the broader creative sector (Fahmi et al., 2017; Florida, 2017; Tao et al., 2019). By examining ICT separately, this study identifies its relationship with the development of other creative activities and provides additional empirical evidence for considering digital technologies within the framework of new industrialization. The results suggest that opportunities for path renewal in remote resource-based settlements are associated not only with technological development but also with the existing structure of local economic activity and spatial relationships between settlements.

CONCLUSION

The findings of this study support the following conclusions. Firstly, the findings provide

confirmation of the research hypothesis: resource-based and single-industry towns of the Far Eastern Federal District in Russia are capable of pursuing creative new industrialization by relying on information and communication activities, even under the substantial influence of path dependence and the spatial factor of transport accessibility. Secondly, this study has identified specific factors influencing the development of creative industries within the Far Eastern Federal District of Russia. Spatial heterogeneity in ICT dynamics is observed in Ulan-Ude, Chita, Krasnokamensk (Zabaikalsky Krai), and Severobaikalsk (Republic of Buryatia). Fixed-asset concentration in creative industries is observed in Luchegorsk, Svetlogorye, and Spassk-Dalny (Primorsky Krai). Wage concentration is observed in Dalnegorsk, Luchegorsk, and Svetlogorye (Primorsky Krai), and Severobaikalsk (Republic of Buryatia). The dynamics of creative industries, conversely, exhibit a spatially neutral response to the influence of locally differentiated factors. Thirdly, a negative spillover effect was observed, whereby the dynamics of creative industries decrease in proximity to single-industry towns characterized by higher wage concentration.

Nevertheless, this study's findings are subject to inherent limitations arising from the selection of resource-based and single-industry towns and regional centres, potentially restricting the generalizability of the results to a broader range of settlements. While a more diverse sample might reveal additional development factors influencing spatial patterns, the homogeneity of the selected settlements facilitated the identification of nuanced relationships and spatial variations amenable to regression modelling, which may not be discernible in a more heterogeneous urban landscape.

The estimation sample is a balanced panel of 26 settlements over ten annual waves (2013–2022), which limits the lag depth and effective degrees of freedom available for dynamic panel diagnostics. The temporal structure among CIGR, ITGR and the concentration measures is modelled using predetermined HHICIFA and HHIW lags (constructed from SPARK data beginning in 2010) and complementary entity fixed-effects Granger-type regressions reported in the Results section. The three-year lag for wage concentration was selected from the set of alternative lags ($t-1$, $t-2$ and $t-3$) using AIC, BIC and the Hannan–Quinn criterion

(with HHICIFA held at $t-1$), and the spatial wage-concentration spillover coefficients were compared across these alternative lag orders.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: IA; research design: IA; data collection: IA; analysis and interpretation: IA; writing draft preparation: IA; supervision: IA; correction of article: IA; proofread and final approval of article: IA. All authors have read and agreed to the published version of the manuscript.

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Artificial Intelligence in the Digital Transformation of Smart City Governance: A Bibliometric Analysis

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ABSTRACT

The rapid introduction of artificial intelligence into smart city management systems is changing approaches to urban planning, public service provision, and management decision-making, but scientific research in this area remains thematically and disciplinarily fragmented. The primary aim of this study is to systematically map the scientific literature on the role of artificial intelligence in the digital transformation of smart city governance. The paper uses methods of bibliometric and network analysis, including analyses of publication and citation dynamics, co-authorship, bibliographic coupling among organizations, and the co-occurrence of keywords. The selection of publications was conducted in accordance with the PRISMA 2020 guidelines, and the construction and visualization of bibliometric networks were performed using the VOSviewer program. The initial data was obtained from the Scopus database on October 5, 2025. An initial search revealed 34,548 documents. After applying the criteria of the subject area, publication period, document type, and language, the final sample included 1,865 English-language journal articles published in 2015-2025. The largest number of publications is in China — 236 articles (12.7%), Great Britain — 230 (12.3%), and the USA — 216 (11.6%). Kazakhstan ranks 54th with nine publications. The most productive journal is Sustainability, with 254 articles, followed by Sustainable Cities and Society with 134 and Cities with 122. The results show a steady increase in scientific interest in the topic after 2019 and, at the same time, indicate a lack of development in interregional scientific cooperation and research on the ethical, institutional, and societal aspects of the use of artificial intelligence in urban governance.

KEYWORDS: Smart City, Urban Planning, Urban Economy, Artificial Intelligence, Digital Transformation, Bibliometric Analysis, Network Analysis

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Искусственный интеллект в цифровой трансформации управления умными городами: библиометрический анализ

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АННОТАЦИЯ

Стремительное внедрение искусственного интеллекта в системы управления умными городами меняет подходы к городскому планированию, предоставлению общественных услуг и принятию управленческих решений, однако научные исследования в этой области остаются тематически и дисциплинарно разрозненными. Цель настоящего исследования систематизировать научную литературу о роли искусственного интеллекта в цифровой трансформации управления умными городами. В работе применены методы библиометрического и сетевого анализа, включая анализ динамики публикаций и цитирования, соавторства, библиографического сопряжения организаций и совместной встречаемости ключевых слов. Отбор публикаций осуществлялся в соответствии с принципами PRISMA 2020, а построение и визуализация библиометрических сетей — с использованием программы VOSviewer. Исходные данные получены из базы Scopus 5 октября 2025 года. Первоначальный поиск выявил 34 548 документов. После применения критериев предметной области, периода публикации, типа документа и языка в итоговую выборку вошли 1 865 англоязычных журнальных статей, опубликованных в 2015–2025 годах. Наибольшее количество публикаций приходится на Китай — 236 статей (12.7%), Великобританию — 230 (12.3%) и США — 216 (11.6%). Казахстан занимает 54-е место с девятью публикациями. Наиболее продуктивным журналом является Sustainability — 254 статьи, за ним следуют Sustainable Cities and Society — 134 и Cities — 122 статьи. Результаты показывают устойчивый рост научного интереса к теме после 2019 года и одновременно свидетельствуют о недостаточной развитости межрегионального научного сотрудничества и исследований этических, институциональных и общественных аспектов применения искусственного интеллекта в городском управлении.

КЛЮЧЕВЫЕ СЛОВА: умный город, городское планирование, городская экономика, искусственный интеллект, цифровая трансформация, библиометрический анализ, сетевой анализ

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INTRODUCTION

Over the past decade, digital technologies have been rapidly integrated into urban governance systems. Artificial intelligence (hereinafter – AI) has attracted increasing attention because of its potential to transform smart city development and management. AI offers numerous opportunities to improve quality of life, increase service efficiency, enhance infrastructure reliability, and support effective urban administration (Albino et al., 2015). It is now used not only to anticipate and prevent infrastructure failures but also to improve public services and promote sustainable development.

AI can support the integration of the core dimensions of smart city development, including the economy, human capital, governance, mobility, the environment, and quality of life (Albino et al., 2015). This integration is enabled by real-time data processing, predictive analytics, automated decision support systems, and coordination among different urban services. In transportation, AI can optimize traffic flows, public transport routes, and mobility planning. In environmental management, it can support the monitoring of energy consumption, emissions, waste, and other indicators of urban sustainability. AI can also facilitate economic development by improving resource allocation, supporting innovation, and increasing the efficiency of urban infrastructure. In public administration, it can strengthen evidence-based planning, automate routine administrative processes, improve public service delivery, and enable authorities to respond more rapidly to citizens' needs. When combined with the Internet of Things, big data, and other digital technologies, AI provides urban authorities with new tools for identifying emerging problems, evaluating alternative policy scenarios, and addressing complex urban development challenges. However, the effectiveness of these applications depends on data quality, institutional capacity, system interoperability, and the responsible governance of AI technologies.

Nevertheless, the body of knowledge on the application of AI in smart city management remains dispersed across various disciplines. The ethical application of AI, protecting privacy, and minimizing potential abuse of AI are among the key concerns that must be addressed in this nascent domain. These concerns have been considered in the current

paper through a bibliometric study. The application of bibliometrics, which involves quantitative approaches in the assessment of scientific literature, is an objective way to analyse new domains and draw the contours of their development.

The primary aim of this study is to systematically map scientific literature on AI's role in the digital transformation of smart city governance. Specifically, the study identifies the major thematic clusters, influential authors, institutions, countries, journals and publications, international collaboration patterns, and existing research gaps. To achieve this aim, Scopus-indexed publications are examined using bibliometric techniques within a systematic literature-selection framework. The study addresses the following research questions:

RQ1: What major themes and research clusters characterize the literature on AI and the digital transformation of smart city governance?

RQ2: Which authors, institutions, countries, journals, and publications have had the greatest influence on the development of this research field?

RQ3: What research gaps and promising directions for future studies emerge from the bibliometric analysis?

LITERATURE REVIEW

In the context of smart cities, urban governance encompasses the institutional arrangements, decision-making processes, and stakeholder relationships through which public policies and urban services are designed, implemented, and evaluated (Meijer & Bolívar, 2016). Effective governance can strengthen urban competitiveness by improving institutional coordination, supporting innovation, and enabling cities to respond more efficiently to social, economic, and environmental challenges (Sgambati & Gargiulo, 2022). Smart city governance therefore extends beyond the digital provision of public services. It also includes citizen participation, evidence-based policymaking, institutional transparency, and the co-production of urban solutions by public authorities, businesses, civil society organisations, and local communities.

Scholl and AlAwadhi (2016) identify several governance challenges associated with smart city initiatives. These include coordinating complex partnerships among public, private, and civic actors, integrating data from different administrative

systems, managing large-scale data infrastructures, and maintaining democratic accountability in an increasingly algorithmic environment. The growing use of AI adds another layer to these challenges because algorithmic outputs can influence policy priorities, resource allocation, access to public services, and administrative decision-making. Consequently, the adoption of AI in urban governance requires not only appropriate technological infrastructure but also institutional rules that determine how data and algorithmic recommendations are produced, interpreted, and used.

The digital transformation of public administration entails the radical reshaping of governmental systems, functions, and relationships through the intelligent use of digital technologies (Mergel et al., 2019). Unlike e-government development, which emphasizes continuous improvement, digital transformation entails reconsidering how values are created, organizational cultures are shaped, and state-citizen relations are formed. According to the literature, digital transformation is the most prominent form of technological change in government administration. Public sector studies have shifted toward an emphasis on data analytics and AI (Sun & Medaglia, 2019). However, public institutions may lack the regulatory capacity, specialised expertise, and organisational flexibility required to adapt governance frameworks to rapidly developing AI capabilities (Wirtz & Weyerer, 2023). Moreover, the public value of digital transformation depends not only on administrative efficiency but also on citizen trust, acceptance, accessibility, and the perceived legitimacy of technology-based decisions (Twizeyimana & Andersson, 2019).

The use of AI in urban governance has broad scope and spans various areas. According to Yigitcanlar and Cugurullo (2020), there is an extensive overview of AI technology for urban development, with machine learning as the main component. This paper finds a vast disparity between the technological aspects of AI and the preparedness of institutions in local governance settings. On the other hand, theoretical research into the new science of cities has postulated that the digital flow of information is transforming urban systems into complex adaptive systems that require new computational models for governance. Such theoretical knowledge has led to a growing body

of research on the role of AI in improving human decision-making in urban governance. On the other hand, the value-related aspects of governance, including fairness, accountability, and political legitimacy, cannot be captured solely by technical approaches (Cocchia, 2014).

However, despite the growing body of studies conducted in both fields, important gaps remain. Firstly, the knowledge structure of literature on the use of AI in smart city governance has yet to be systematically mapped through bibliometric analysis. Secondly, few cross-country comparisons have been made on the use of AI in governance practices. The third gap concerns the ethical and accountability aspects of AI in smart city management, including transparency and citizen involvement. The fourth gap concerns the absence of a temporal analysis to demonstrate the evolution of research priorities in response to new policies and technologies. This study fills these gaps by providing an empirical basis for further research.

Bibliometric analysis is well-suited to addressing these gaps because it enables quantitative examination of publication trends, citation impact, collaboration networks, influential contributors, and relationships among research topics (Donthu et al., 2021). Previous research has demonstrated the increasing relevance of digital public administration for sustainable development and data-driven governance (Burlacu et al., 2021). However, an integrated mapping of AI research within the specific context of smart city governance remains necessary. Accordingly, the present study analyses Scopus-indexed publications to identify the intellectual structure, thematic clusters, influential contributors, collaboration patterns, and future research directions in this field.

RESEARCH METHODS

Bibliometrics is an established methodology that uses quantitative approaches to assess trends in scientific literature (Donthu et al., 2021). In this regard, a bibliometric analysis of scientific literature on the role of AI in the digital transformation of smart city governance in the Scopus database was performed, with a particular focus on the volume of literature and citation rate, collaboration networks among authors, and thematic clusters of keywords. The advantage of using a bibliometric

approach lies in its capability to analyse large sets of literature at once, reveal structural patterns, and offer a methodological foundation for intellectual developments.

Scopus was selected as the sole bibliographic data source because it provides broad multidisciplinary coverage and structured metadata required for bibliometric analysis, including author information, institutional affiliations, citation data, author

keywords, and cited references. The publication identification, screening, and selection procedure was reported in accordance with the PRISMA 2020 framework, adapted to the context of a bibliometric review (Page et al., 2021). PRISMA was used to document the number of records identified, excluded, screened, and retained for the final bibliometric analysis. Figure 1 presents the corresponding study-selection flow diagram.

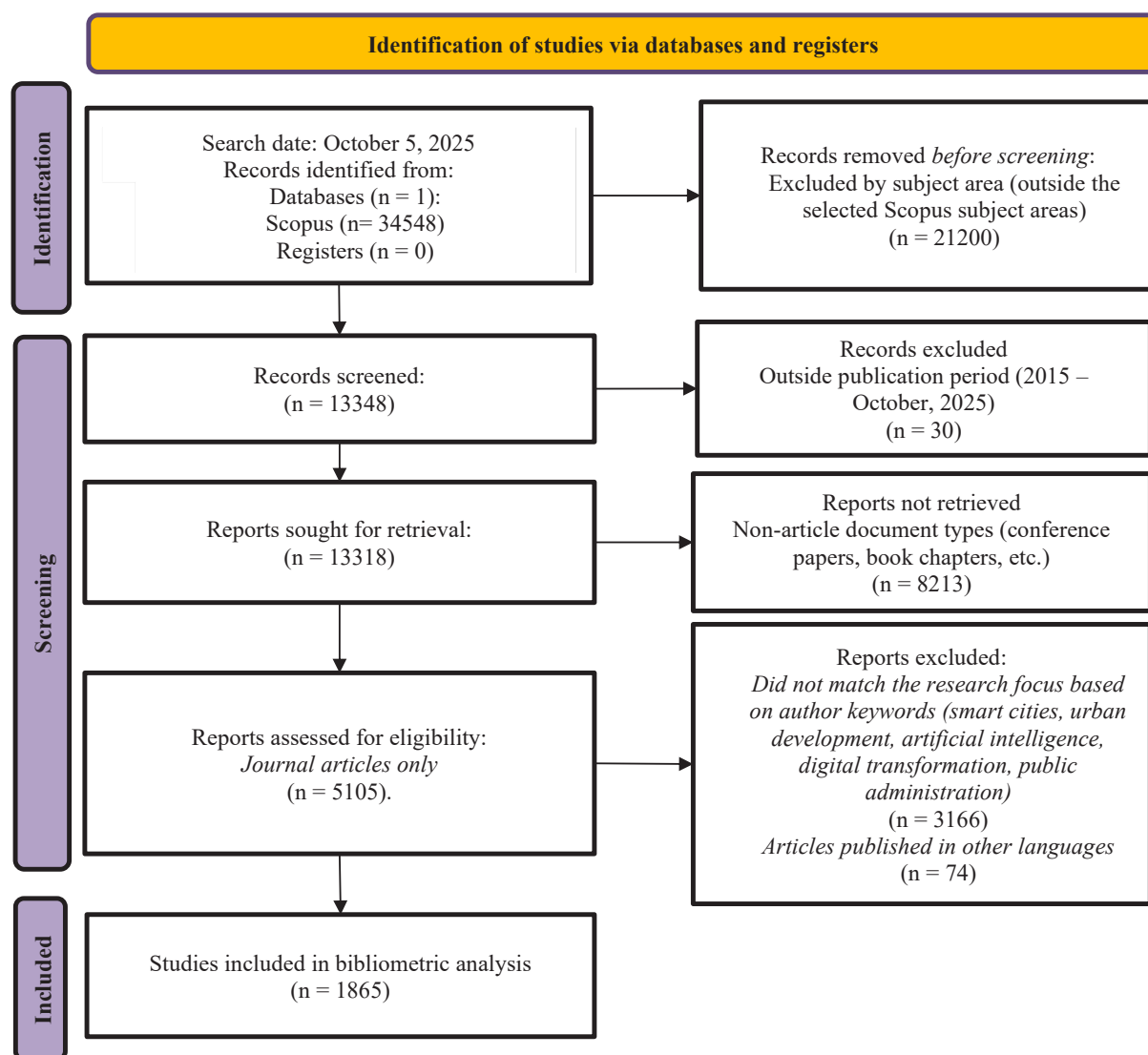


Figure 1. PRISMA 2020 flow diagram of the study selection process

Bibliometric data were retrieved exclusively from the Scopus database on 5 October 2025. The search was conducted in the TITLE-ABS-KEY field using three conceptual groups representing smart cities, artificial intelligence, and urban governance: TITLE-ABS-KEY (“smart city” OR “smart cities”)

AND TITLE-ABS-KEY (“artificial intelligence” OR “machine learning” OR “deep learning”) AND TITLE-ABS-KEY (“urban governance” OR “smart governance” OR “public administration” OR “digital government” OR “digital transformation” OR “urban management”). This search structure

ensured that every retrieved publication addressed all three core components of the study: the smart city context, artificial intelligence technologies, and governance or public administration. The acronym “AI” was not used as an independent search term because it may retrieve records in which the same abbreviation has a different meaning.

The initial search returned 34,548 records. Following the PRISMA 2020 guidelines, publications outside the selected subject areas (Social Sciences, Decision Sciences, Business, Management and Accounting) were excluded ($n = 21,200$), leaving 13,348 records for screening. Restricting the publication period to 2015-2025 (October) excluded 30 records, resulting in 13,318 publications. Subsequently, only journal articles were retained, excluding conference papers, reviews, book chapters, editorials, and other non-article document types ($n = 8,213$). This resulted in 5,105 journal articles eligible for further assessment.

The bibliographic records were exported from Scopus in CSV format. The exported data included complete citation information, abstracts, author affiliations, author keywords, index keywords, funding information, and cited references. Before analysis, author names, institutional affiliations, country names, and synonymous keywords were standardised. A thesaurus file was used to merge equivalent terms, such as “AI” and “artificial intelligence”, “smart city” and “smart cities”, and “IoT” and “Internet of Things”.

The remaining 1,939 publications were further restricted to English-language articles, excluding 74 non-English publications. Consequently, a final dataset of 1,865 publications was retained for bibliometric analysis. The inclusion criteria comprised peer-reviewed journal articles indexed in Scopus that satisfied the predefined search query, subject area, publication period, author keyword filters, and English-language criteria.

The bibliographic records were exported in CSV format and included complete bibliographic information, author affiliations, abstracts, author

keywords, and cited references for subsequent bibliometric analysis using VOSviewer. To identify collaboration networks and thematic research clusters, network analysis was conducted using VOSviewer based on co-authorship relationships and keyword co-occurrence. In the resulting maps, the colours represent clusters identified using the VOSviewer clustering algorithm (Van Eck & Waltman, 2010).

RESULTS

Within the framework of the bibliometric analysis, the study examined research on the role of AI in public administration and urban development by analysing journals, highly cited publications, authors, and keywords in the dataset. This approach enabled the construction of bibliometric maps and provided the analytical basis for answering the research questions.

The dataset used in this study comprises 1,865 scholarly papers published in 687 journals, primarily covering the fields of Social Sciences, Business, Management and Accounting, and Decision Sciences. These papers were authored by 5,350 researchers affiliated with 3,443 organisations in 102 countries and received a total of 74,421 citations.

The annual number of publications demonstrates an overall upward trend during the period under consideration. From 2015 to 2018, scientific output remained relatively low, reflecting the early development of this interdisciplinary research field. A notable increase occurred in 2019, when the number of publications reached 139. Although some fluctuations were observed between 2020 and 2022, a clear upward trend emerged after 2023. During the first ten months of 2025, the annual number of publications exceeded 287. Overall, these findings demonstrate a gradual increase in scientific activity in this field.

Citation counts for these years are expected to increase over time (Figure 2).

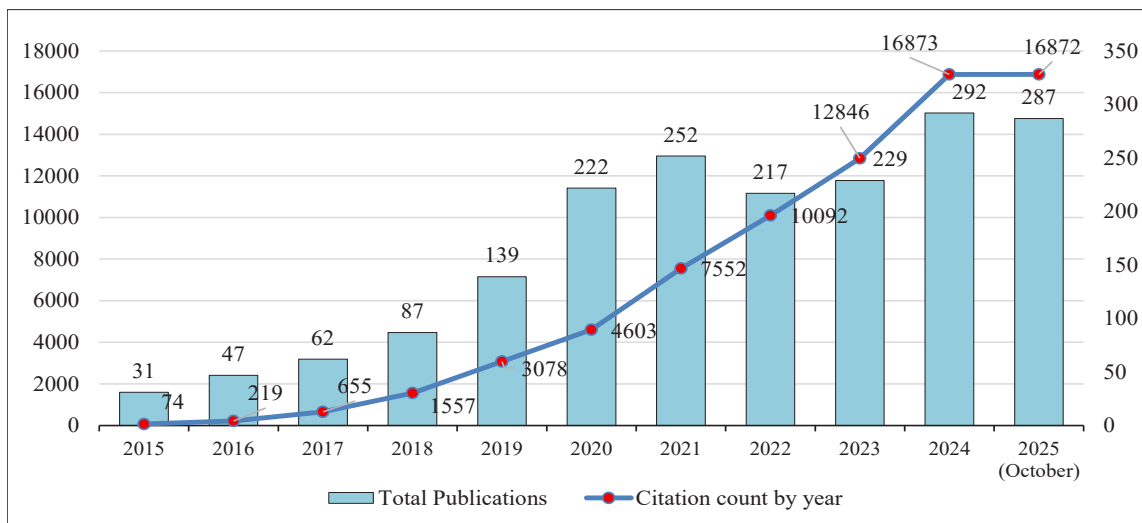


Figure 2. Annual publication and citation index

Regarding citation dynamics, the publications received between 74 and 655 citations per year from 2015 to 2017. The number of citations increased sharply to 1,557 in 2018, possibly due to the influence of one or more highly cited studies. From 2019 onwards, citation counts continued to increase, reaching 3,078. The highest citation activity was observed during the 2020–2025 period, indicating the growing visibility and academic influence of

publications in this field. Citation data for 2024 and 2025 remain incomplete because recent publications have had less time to accumulate citations, and the 2025 data cover only through October.

Figure 3 presents the international co-authorship network by country, illustrating collaborative relationships among countries engaged in smart city research.

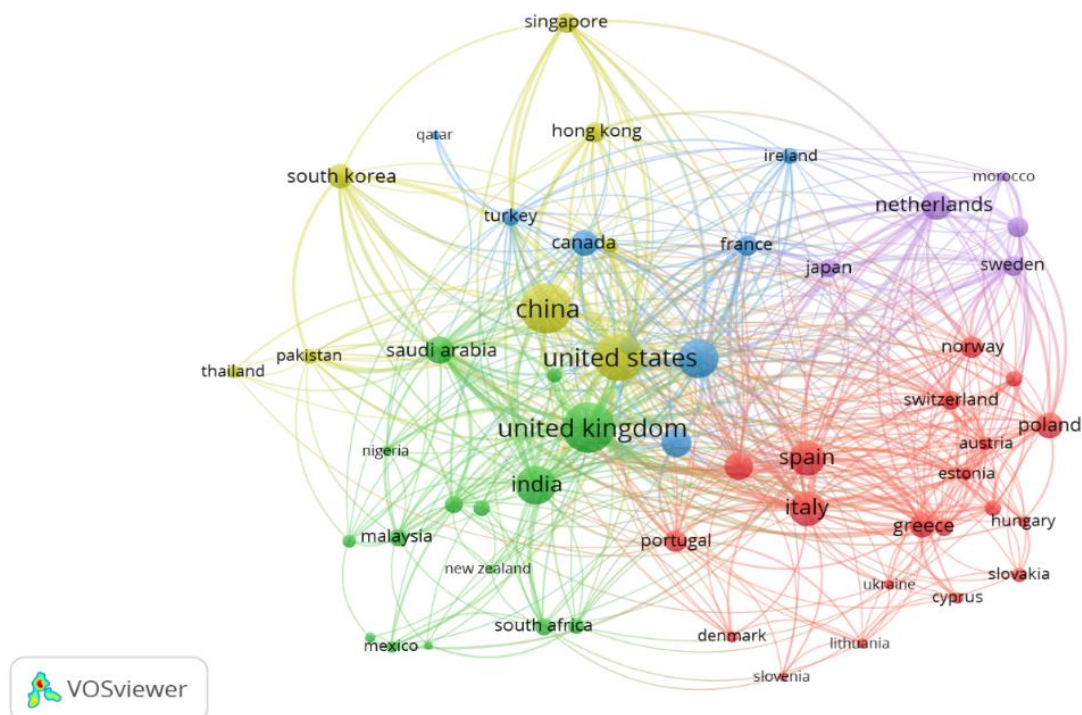


Figure 3. International co-authorship network by country

The network revealed several densely connected international collaboration clusters, with the United States, China, and the United Kingdom occupying central positions and maintaining strong collaborative links with numerous countries. These findings demonstrate that international scientific cooperation plays an important role in the development of smart city research. China had the highest publication output ($n = 236$; 12.7% of all publications), followed by the United Kingdom ($n = 230$; 12.3%), the United States ($n = 216$; 11.6%), India ($n = 144$; 7.7%), Australia ($n = 137$; 7.3%), Italy ($n = 119$; 6.4%), and Spain ($n = 118$; 6.3%).

Although China led in publication output, the citation analysis showed that publications from the United States had the highest citation impact per document ($CPD = 22.7$), followed by those from the United Kingdom ($CPD = 19.7$). Kazakhstan ranked 54th with 9 publications, indicating a relatively limited contribution to global scientific output in this field.

The bibliographic coupling network of organizations generated using VOSviewer illustrates the intellectual similarity among research institutions based on the references cited in their publications (Figure 4).

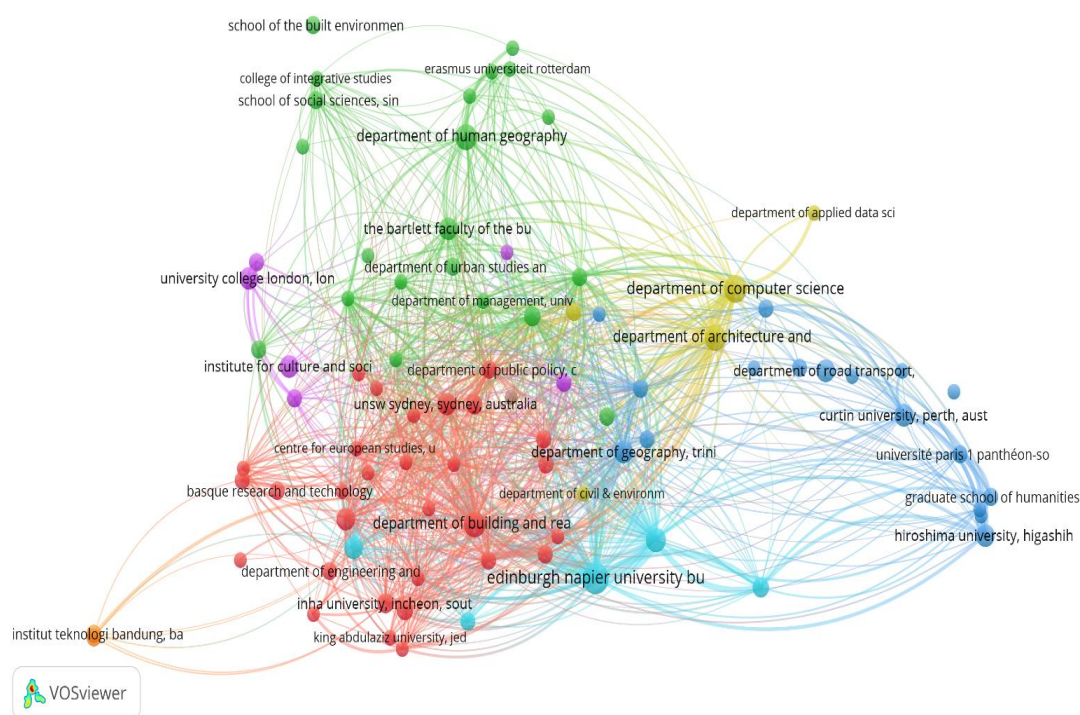


Figure 4. Bibliographic coupling of organizations

The network identifies several densely connected institutional clusters, indicating organizations that share similar knowledge bases and research interests rather than direct collaborative relationships. The clustering patterns reflect thematic proximity in smart city research and demonstrate the existence of distinct research communities. Among the most influential organizations, Queensland University of Technology ($n = 25$) and UNSW Sydney ($n = 25$) exhibit the highest publication output. UNSW Sydney occupies a central position within the network and demonstrates strong bibliographic links with organizations across multiple thematic clusters,

reflecting the broad interdisciplinary scope of its research. Edinburgh Napier University ($n = 21$) also represents a prominent organization, connecting several institutional clusters through shared citation patterns in smart city and urban planning research. The National University of Singapore ($n = 20$) forms the core of the Asian institutional cluster, showing strong bibliographic coupling with organizations from Southeast Asia, particularly Institut Teknologi Bandung (Indonesia). University College London ($n = 18$) occupies a central position within the United Kingdom-Europe cluster and demonstrates high intellectual similarity with institutions

engaged in theoretical and conceptual research. Norges Teknisk-Naturvitenskapelige Universitet ($n = 17$) represents the Scandinavian research community and exhibits strong bibliographic links with organizations focusing on engineering and urban technology. Overall, the bibliographic coupling network indicates that organizations tend to form geographically and thematically coherent clusters based on shared citation patterns. While the Australian, United Kingdom, European, and Asian clusters demonstrate strong internal bibliographic similarity, the links between these clusters are comparatively weaker. Organizations such as

UNSW Sydney and Edinburgh Napier University occupy central positions connecting multiple thematic clusters, reflecting their broad research portfolios and extensive intellectual influence within the smart city research domain.

Co-authorship networks of scholars show how scientists work together to develop and contribute to the field of research. In the case study at hand, the co-authorship network comprises 5,350 scholars whose interactions were examined with a minimum publication threshold of 5, yielding 6 clusters comprising 24 authors (Figure 5).

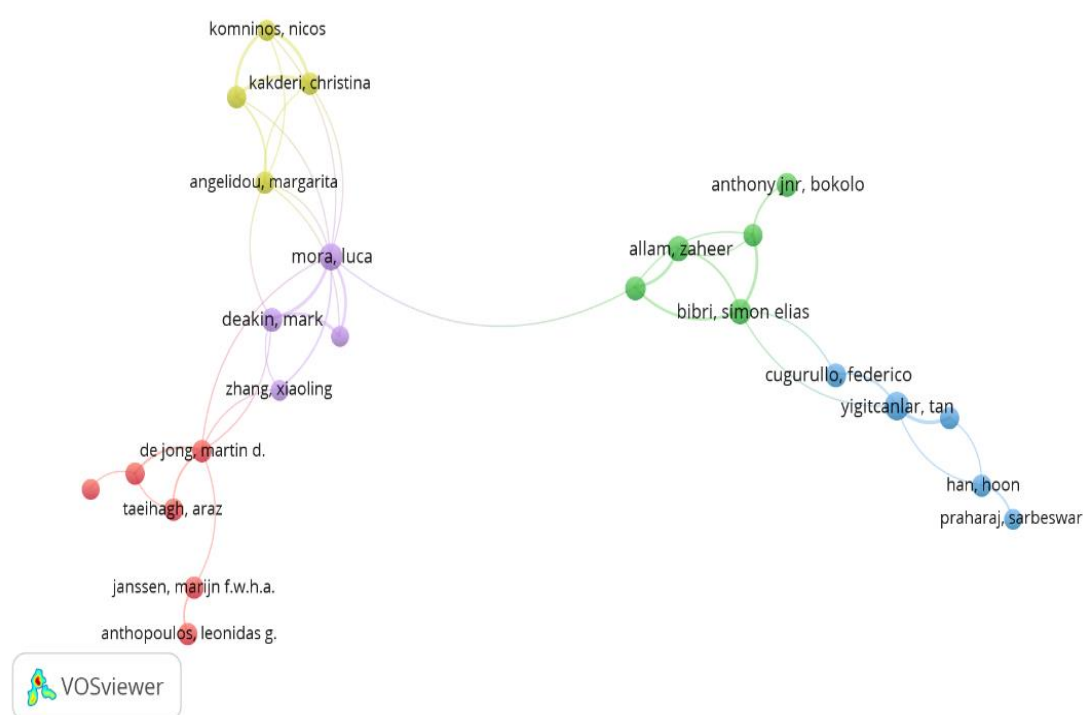


Figure 5. Co-authorship network among authors

The formation of clusters in the network indicates that each group consists of authors with relatively strong collaborative ties. These clusters are characterized by high levels of internal connectivity and comparatively limited links with other clusters. Larger nodes represent authors with greater weight in the co-authorship network, while extensive links with other researchers indicate their potential role in connecting different research directions.

The largest author cluster is centered on Tan Yigitcanlar and includes researchers from Australia, Ireland, and Asia. The map shows that this cluster is strongly connected to Zaheer Allam and Simon

Elias Bibri, reflecting collaboration among scholars working on smart-city sustainability and green-infrastructure development. Another cluster comprises Greek researchers, including Margarita Angelidou, Christina Kakderi, Nicos Komninos, and Anastasia Panori, whose research focuses on smart city innovation and regional development. The network also reveals links among Mark Deakin, Luca Mora, Alasdair Reid, and Xiaoling Zhang, indicating collaboration between researchers from Europe and Asia. Luca Mora occupies a central position in the network and appears to act as a bridge between several research clusters.

The co-authorship visualization helps identify existing collaboration patterns and the formation of scientific communities within the multidisciplinary field of smart city governance. Although cross-regional links are present, they remain less developed than collaboration within individual geographical and thematic clusters. This pattern

demonstrates the international scope of smart city research and underscores the need to strengthen cooperation among researchers across regions.

As shown in Figure 6, studies on the digital transformation of urban governance are concentrated in several core journals.

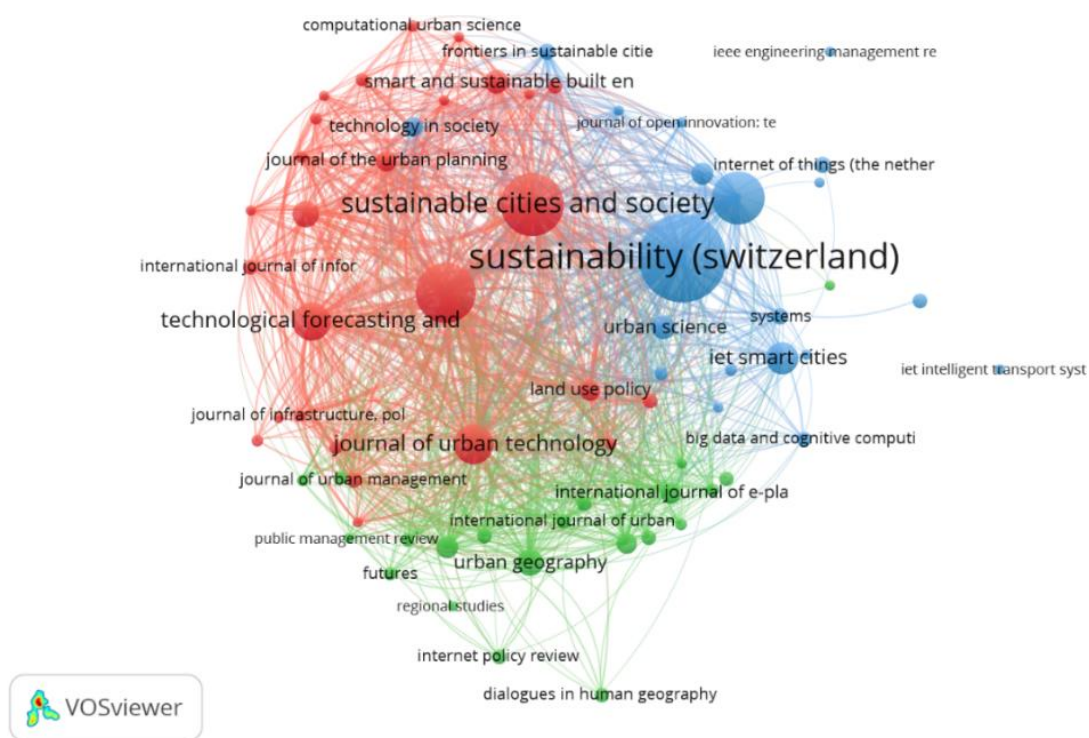


Figure 6. Bibliometric map of international scientific journals

The review revealed that many studies regarding digital transformation in urban governance are available in specific core journals. When it comes to journal impact, the largest number of papers ($n = 254$) is found in Sustainability (Switzerland), a journal attributed to its interdisciplinary nature and open-access policy. Sustainable Cities and Society is another key journal in the field, ranking second ($n = 134$). Another noteworthy journal in the field

is Cities ($n = 122$), one of the most authoritative sources in the study of AI and smart-city governance. Other impactful journals include Smart Cities ($n = 92$), Journal of Urban Technology ($n = 53$), Technological Forecasting and Social Change ($n = 48$), and IET Smart Cities ($n = 35$).

The ten most highly cited scientific papers are presented in Table 1.

Table 1. Top ten most cited publications

Author (year)	Title	Journal and No.	Citations
Albino et al. (2015)	Smart cities: Definitions, dimensions, performance, and initiatives	Journal of Urban Technology, 22(1), pp. 3–21	2,636
Moreno et al. (2021)	Introducing the “15-minute city”: Sustainability, resilience and place identity in future post-pandemic cities	Smart Cities, 4(1), pp. 93–111	1,210
Ahvenniemi et al. (2017)	What are the differences between sustainable and smart cities?	Cities, 60, pp. 234–245	1,089
Allam & Dhunny (2019)	On big data, AI and smart cities	Cities, 89, pp. 80–91	881
De Jong et al. (2015)	Sustainable-smart-resilient-low carbon-eco-knowledge cities; Making sense of a multitude of concepts promoting sustainable urbanization	Journal of Cleaner Production, 109, pp. 25–38	874
Dagher et al. (2018)	Ancile: Privacy-preserving framework for access control and interoperability of electronic health records using blockchain technology	Sustainable Cities and Society, 39, pp. 283–297	773
Angelidou (2015)	Smart cities: A conjuncture of four forces	Cities, 47, pp. 95–106	691
Shelton et al. (2015)	The 'actually existing smart city'	Cambridge Journal of Regions Economy and Society, 8(1), pp. 13–25	676
Appio et al. (2019)	Understanding Smart Cities: Innovation ecosystems, technological advancements, and societal challenges	Technological Forecasting and Social Change, 142, pp. 1–14	528
Ahad et al. (2020)	Enabling technologies and sustainable smart cities	Sustainable Cities and Society, 61, 102301	503

Note: compiled by the authors

The criterion for selecting publications is the number of citations, starting at 500. The leader is the publication of Albino, V., Berardi, U., and Dangelico, R.M., entitled “smart cities: definitions, dimensions, performance, and initiatives”, dated 2015 and published in the Journal of Urban Technology. It has been cited 2,636 times. Second is the paper of Moreno, C., Allam, Z., Chabaud, D., Gall, C., and Pratlong, F. “Introducing the ‘15-minute city’: Sustainability, resilience and place identity in future post-pandemic cities” (1,210 citations). The study by Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., and Airaksinen, M., entitled “What are the differences between sustainable and smart cities?”, has also provided significant insights into policy issues in smart city governance. It is worth noting that the papers discussed touch on key aspects of digital transformation and urban governance. In turn, it should be noted that highly cited publications generally require time to gain widespread recognition, as citation counts are often considered an indicator of their impact.

Keyword co-occurrence analysis is a widely used bibliometric technique for identifying the conceptual structure and major research themes within a scientific field. It examines the frequency of author keywords and their co-occurrence relations across publications. A keyword co-occurrence map enables researchers to identify the principal research themes and conceptual relationships in the literature on digital transformation in urban governance. In the present study, keyword co-occurrence analysis was performed using author keywords extracted from the selected publications. A total of 9,174 author keywords were identified across the 1,865 articles. To improve the interpretability of the network, a minimum occurrence threshold of 10 was applied. Consequently, 307 keywords met the threshold and were included in the co-occurrence network. Using the VOSviewer modularity optimization algorithm, the keyword co-occurrence network was partitioned into four thematic clusters (Figure 7).

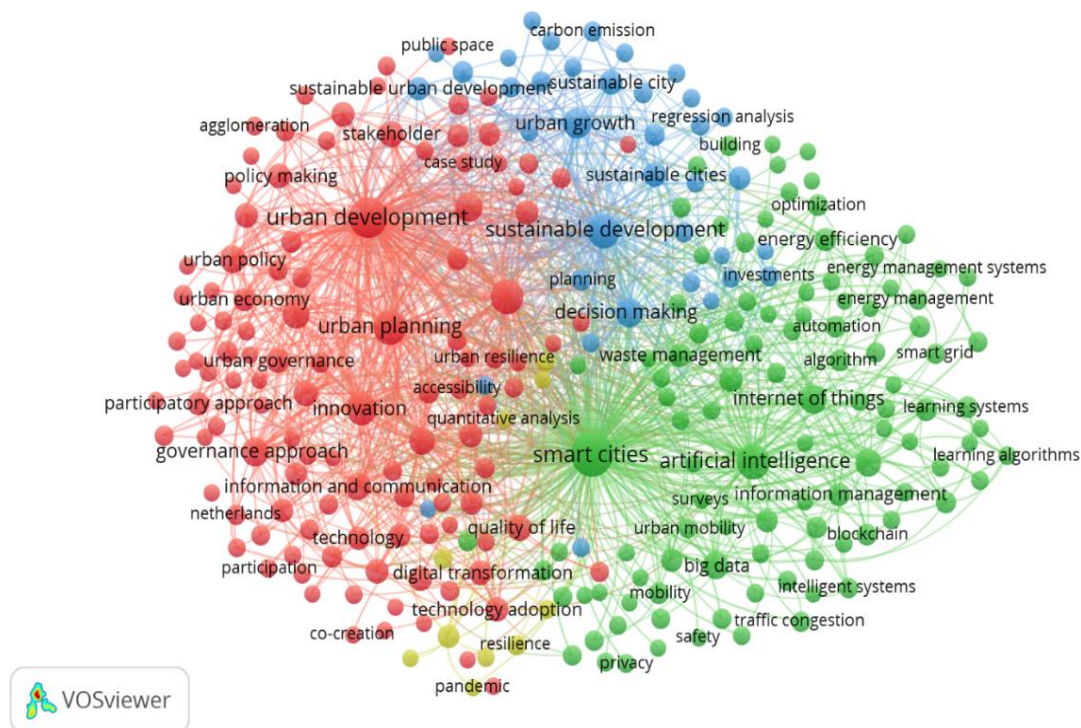


Figure 7. Co-occurrence keyword network

According to the keyword co-occurrence analysis, the keyword “smart cities” had the highest occurrence frequency ($n = 1,106$) and the highest total link strength ($TLS = 4,951$), indicating that it represents the most influential and strongly connected node within the network and serves as the central hub linking the identified thematic clusters. Other frequently occurring keywords included urban development ($n = 657$), sustainability ($n = 303$), artificial intelligence ($n = 288$), innovation ($n = 173$), internet of things ($n = 125$), decision making ($n = 122$), and big data ($n = 90$). The proximity of the “artificial intelligence” node to the central “smart cities” node indicates a strong thematic relationship between these concepts within the keyword co-occurrence network. Overall, the network reveals the principal thematic directions of smart city research and highlights the increasing importance of AI in the digital transformation of urban systems.

Firstly, the cluster marked in green (technological) primarily focuses on the keywords “smart cities” and “artificial intelligence”. In the network map, this cluster has a high number of connections among the nodes, which are related to terms such as “internet of things”, “urban mobility”, “big data”, “information management”,

and “blockchain”. The formation of this group of keywords shows their interdependency and interrelatedness. The scientific importance of this cluster lies in its potential to create the technological infrastructure for the effective implementation of big data and ICT by integrating AI into the sustainable development of smart cities. AI plays an important role in innovation that relies on big data and IoT, providing opportunities for data analysis and prediction. The authors Akgün et al. (2024) stress the necessity of using digital communication channels between citizens and authorities to ensure the city’s adaptation to the digital age. According to Cardona-Arenas and Campuzano (2024), this cluster creates a technological basis for implementing “a collaborative society that tackles urban problems thanks to citizen participation”.

The second cluster, shown in red (governance), revolves around the keywords “urban development” and “urban planning”. This cluster has the most nodes and spans a wide area on the left side of the network. This cluster consists of ideas such as “innovation”, “information and communication”, “participation”, “urban governance”, “urban economy”, and “digital transformation”. The scientific contribution of this cluster is evident

in the network model through the need for interaction and cooperation between citizens and local authorities in urban planning, as well as the principle of transparency in public administration. While the technological base introduced in the first cluster (big data, IoT) operates as an intermediary node, contributing to the accomplishment of goals in “urban planning” and “urban governance”, it connects the two clusters. In particular, as Han et al. (2024) point out, when local governments follow the principles of openness in data collection, it becomes easier to disseminate information about urban planning among citizens. Furthermore, Kong and Chen (2025) emphasize that the agency for transformation exercised by local governments is essential for increasing urban efficiency. This is directly related to the open community participation mentioned in the first cluster.

Thirdly, the blue cluster (“sustainability”) focuses on keywords such as “sustainable development” and “urban growth”. This cluster incorporates concepts including “decision-making”, “sustainable cities”, “sustainable urban development”, “carbon emission”, “building”, “regression analysis”, and “planning”. Its position within the network indicates strong thematic connections with both the technological and governance clusters. The inclusion of regression analysis reflects the widespread use of empirical methods to examine relationships among urban growth, environmental sustainability, and carbon emissions. Villani et al. (2025) demonstrate that Digital Twin technology, when supported by sensor-distributed networks and predictive capabilities, can enhance sustainable urban management, urban resilience, and data-driven decision-making. Similarly, Kireyeva et al. (2022) emphasize that regional digital readiness and ICT development constitute essential prerequisites for implementing smart city initiatives and supporting regional digital transformation.

Fourthly, the yellow cluster (economic development) focuses on “economic development”, “investments”, “regional development”, “smart grid”, “energy management”, and “optimization” and related topics. The proximity of this cluster to the green (technological) one illustrates that, at the level of the network itself, AI’s influence on the economy and automation more broadly is evident, as AI algorithms directly affect economic outcomes. Moreover, the cluster in question relies on the

results from the first three clusters but focuses more on the investment and economic growth aspects of digital transformation in urban governance. Therefore, it can be viewed as a bridge between theoretical insights and practical economic/administrative decision-making in urban settings. According to Alrasbi and Ariaratnam (2026), digital transformation within the public sector occurs by creating particular “smart city” strategies, which highlights the importance of the cluster in question. Political and economic specifics of each region are highly relevant for overcoming issues associated with smart city development.

In terms of science, the innovation is the systematic mapping of four interrelated aspects of urban governance during the process of digital transformation, using a keyword co-occurrence network, and the interrelations among them are empirically demonstrated by the density of network connections. The introduction of AI and other technological innovations in the public sector improves mechanisms for interaction and cooperation in urban governance and positively impacts citizens’ well-being. In particular, the application of AI to data analysis and decision-making optimization improves the efficiency of these mechanisms.

DISCUSSION

The bibliometric analysis results reveal that the field under study is marked by high dynamics, increased diversity, and fragmentation.

The keyword co-occurrence analysis identified four major thematic clusters representing the intellectual structure of the field: (1) technological, (2) governance, (3) sustainability, and (4) economic development. The technological cluster emphasizes AI, the IoT, big data, and digital infrastructure. The governance cluster focuses on urban governance, public administration, citizen participation, urban planning, and digital transformation. The sustainability cluster highlights environmentally sustainable urban development, carbon neutrality, and smart sustainable cities, whereas the economic development cluster addresses investment, regional development, energy management, and smart-city economic strategies. Together, these four clusters illustrate the multidisciplinary structure of AI research in smart city governance.

The significant increase in publications starting in 2019 is explained by the evolution of AI methodologies and the intensification of international policies promoting smart city development.

The visibility of AI-based approaches in the network, expressed in terms of node size, connection intensity, and number of publications, reflects the nature of the field, which is predominantly concerned with showcasing technical feasibility and operational advantages that result from implementing AI. Such a state of affairs aligns with the general tendency noted by Wirtz and Weyerer (2023), in which the implementation of AI in public administration outpaced the development of the necessary theoretical and normative apparatus to manage its social impact.

The bibliometric analysis confirms the need for an in-depth discussion of AI's influence on the digital transformation of smart cities. The findings are consistent with previous studies (Almulhim, 2025; Rouky et al., 2025; Gil et al., 2026), demonstrating that AI contributes to urban infrastructure optimization, energy management, traffic control, and data-driven decision-making. At the same time, smart city research continues to be driven primarily by technological infrastructure, while governance-oriented studies are becoming increasingly prominent. Although China and the United States dominate publication output, European institutions remain particularly influential in governance-oriented research.

From a theoretical point of view, the research will make an additional contribution to the development of knowledge about the use of AI, which should be treated not only as a technological element in smart city infrastructure but also as a central element of governance.

From a practical perspective, the study's results have several implications for action. For policymakers and the urban public sector, these results demonstrate the necessity of designing AI governance models that are developed together with citizens through transparent mechanisms. The lack of studies dedicated to the ethics of AI reveals the increasing need to prepare AI technologies that are designed to be accountable by default. Researchers, in turn, should be aware of the low levels of international cooperation in studies on AI governance in smart cities.

CONCLUSION

The study aimed to analyse the influence of AI on the digital transformation of smart city governance and to examine the intellectual structure and collaboration patterns of the scientific literature using bibliometric methods. The bibliometric analysis of 1,865 Scopus-indexed publications from 2015 to October 2025 yielded several significant findings.

First, the research field has experienced a significant increase in publications since 2019. Although publication output fluctuated between 2020 and 2022, sustained growth resumed after 2023. This trend can be attributed to the increasing maturity of AI technologies and the growing interest of policymakers in their implementation within smart cities. Second, China, the United Kingdom, and the United States stand out as the most active contributors to research. Third, the keyword co-occurrence analysis identified four major thematic clusters representing the intellectual structure of the field: technological, governance, sustainability, and economic development. Together, these clusters indicate that AI research in smart city governance has evolved into a multidisciplinary field integrating technological innovation, governance mechanisms, sustainable urban development, and economic transformation. Fourth, the interaction between citizens and local authorities demonstrates the growing significance of data-driven policymaking. In this sense, the effective exploitation of data through AI and digital transformation technologies becomes a vital part of efficient urban planning and policymaking. Finally, collaboration networks exhibit strong regional cohesion, whereas interregional collaboration remains comparatively limited. The theoretical contributions made between 2015 and 2018 continue to inform the intellectual structure of the field, complemented by an emerging citation layer tied to studies in AI for governance.

Such findings bring a number of additions to the current literature. Methodologically speaking, the use of bibliometric analysis enables researchers to understand the current state of the field and to draw the first-ever map of the topics that constitute it and their relations. Generally, these data provide insight into the structural fragmentation of the research area, which is important for the field itself, and allow for the suggestion of ideas for future

research. Empirically, the research reveals certain communities of researchers, prominent authors, and knowledge brokers who could contribute to the faster and more effective integration of technological and governance perspectives on digital transformations. Therefore, this study provides a solid foundation for future research on the adoption and impact of AI technologies in smart cities.

Some areas for future research are outlined below. Researchers in public administration could investigate the impact of implementing AI governance on urban governance, particularly regarding transparency and intersectoral collaboration. Longitudinal qualitative research on citizens' experiences with AI use in smart-city service delivery would supplement bibliometric mapping with empirical findings. In addition, this highlights the need for additional research on the construction of inclusive cities.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: SZ and SU; research design: SZ, GT, SU, BZ and DY; data collection: SZ, SU and DY; analysis and interpretation: SU, BZ and DY; writing draft preparation: SZ, GT, SU, BZ and DY; supervision: SZ, GT, SU, BZ and DY; correction of article: SZ, GT, SU, BZ and DY; proofread and final approval of article: BZ and DY. All authors have read and agreed to the published version of the manuscript.

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Institutional Support and Women's Economic Resilience: A Sequential Capability-Building Model

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ABSTRACT

Women play an important role in domestic enterprises in the fishing sector, but the mechanisms through which institutional support contributes to sustainable livelihoods remain poorly understood. This study aims to develop and validate a sequential capability-building model explaining how institutional support contributes to livelihood resilience among women operating household-based smoked fish enterprises in Indonesia. The study uses a consistent research design of mixed methods combining historical analysis and structural equation modeling using the partial least squares (PLS-SEM) method. The study analyzed materials from 2014-2024 from 40 documentary sources and 20 interviews, and surveyed 368 women employed in domestic enterprises in Tegalsari, Central Java. The results showed that institutional support positively affects women's economic agency ($\beta = 0.697$, $p < 0.001$) and entrepreneurial orientation ($\beta = 0.164$, $p = 0.005$). Women's economic agency enhances entrepreneurial orientation ($\beta = 0.727$, $p < 0.001$) and the ability to market innovation ($\beta = 0.444$, $p < 0.001$), but it has no statistically significant direct impact on the sustainability of livelihoods ($\beta = 0.138$, $p = 0.149$). Entrepreneurial orientation has the strongest direct impact on livelihood sustainability ($\beta = 0.588$, $p < 0.001$), while market innovations also have a significant impact ($\beta = 0.203$, $p = 0.005$). The results obtained confirm a consistent process of opportunity formation, in which institutional support is transformed into sustainable livelihoods primarily through women's economic agency, entrepreneurial orientation, and the ability to innovate in the market.

KEYWORDS: Entrepreneurship, Women's Entrepreneurship, Entrepreneurial Practice, Gender Equality, Household Economics, Small Business, Indonesia

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Институциональная поддержка и экономическая устойчивость женщин: последовательная модель формирования потенциала

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АННОТАЦИЯ

Женщины играют важную роль в домашних предприятиях рыбного сектора, однако механизмы, посредством которых институциональная поддержка способствует устойчивости средств к существованию, остаются недостаточно изученными. Цель исследования — разработать и валидировать последовательную модель формирования возможностей, объясняющую, каким образом институциональная поддержка способствует устойчивости средств к существованию женщин, занятых в домашних предприятиях по переработке копченой рыбы в Индонезии. В исследовании использован последовательный исследовательский дизайн смешанных методов, объединяющий исторический анализ и моделирование структурными уравнениями методом частичных наименьших квадратов (PLS-SEM). Исследование включало анализ материалов за 2014–2024 гг. на основе 40 документальных источников и 20 интервью, а также опрос 368 женщин, занятых в домашних предприятиях в Тегалсари, Центральная Ява. Результаты показали, что институциональная поддержка положительно влияет на экономическую агентность женщин ($\beta = 0.697$, $p < 0.001$) и предпринимательскую ориентацию ($\beta = 0.164$, $p = 0.005$). Экономическая агентность женщин усиливает предпринимательскую ориентацию ($\beta = 0.727$, $p < 0.001$) и способность к рыночным инновациям ($\beta = 0.444$, $p < 0.001$), однако ее прямое влияние на устойчивость средств к существованию статистически незначимо ($\beta = 0.138$, $p = 0.149$). Предпринимательская ориентация оказывает наиболее сильное прямое влияние на устойчивость средств к существованию ($\beta = 0.588$, $p < 0.001$), тогда как влияние рыночных инноваций также является значимым ($\beta = 0.203$, $p = 0.005$). Полученные результаты подтверждают последовательный процесс формирования возможностей, в рамках которого институциональная поддержка трансформируется в устойчивость средств к существованию преимущественно через экономическую агентность женщин, предпринимательскую ориентацию и способность к рыночным инновациям.

КЛЮЧЕВЫЕ СЛОВА: предпринимательство, женское предпринимательство, предпринимательская практика, гендерное равенство, экономика домохозяйств, малый бизнес, Индонезия

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INTRODUCTION

Small-scale fisheries are among the world's most important socio-economic sectors, supporting food security, employment, and livelihood sustainability for millions of coastal households, particularly in developing countries (Baremore et al., 2021; Owusu & Adjei, 2021). Beyond capture fisheries, household-based fish processing and value-added activities have become increasingly important for generating income, creating employment opportunities, and strengthening the resilience of coastal economies amid environmental, economic, and market uncertainty (Amadu et al., 2021; Fabinyi et al., 2022; Warren & Steenbergen, 2021). Women play indispensable roles throughout these fisheries value chains as processors, traders, entrepreneurs, and household financial managers whose decisions directly influence production continuity and family welfare. Despite these substantial contributions, women operating small-scale fisheries enterprises continue to face persistent institutional barriers, including limited access to financial resources, entrepreneurial training, market information, and formal support systems, which constrain their ability to expand businesses and sustain resilient livelihoods (Harper et al., 2020; Macusi et al., 2023). These challenges suggest that strengthening livelihood resilience requires not only greater economic participation but also a deeper understanding of how institutional support can progressively develop women's entrepreneurial capabilities within household-based fisheries enterprises.

Previous studies have consistently demonstrated that institutional support enhances women's participation in fisheries value chains through capacity-building programs, financial inclusion, and market facilitation (Ayilu et al., 2023; Freeman & Svendsen, 2022; Garza-Gil et al., 2020), while other studies have shown that women's economic agency contributes positively to household welfare, enterprise development, and community resilience (Hosseini, 2021; Malhotra et al., 2024). Likewise, entrepreneurial orientation and innovation capability have been recognized as important drivers of competitiveness and business performance among micro- and small-scale enterprises (Adetoyinbo et al., 2025; Golla & Rao, 2020). However, most existing studies have adopted cross-sectional approaches that examine these factors as independent or partially

connected determinants at a single point in time. Consequently, limited attention has been devoted to understanding how women's economic roles have evolved historically and how long-term institutional transformations shape entrepreneurial capability and livelihood resilience within women-led fisheries enterprises (Barrios et al., 2020; Nthawane & Matanzima, 2023; Thomas et al., 2021).

From a theoretical perspective, previous research has predominantly relied on individual theoretical lenses to explain women's participation and livelihood development in small-scale fisheries. Institutional Theory primarily emphasizes how formal institutions influence access to resources and support systems (Fauzi & Sheng, 2022; Khattak et al., 2021), whereas Women's Economic Agency Theory focuses on women's autonomy in economic decision-making and control over productive resources (Hing et al., 2022; Rodríguez-Satizábal et al., 2025). Entrepreneurial Orientation Theory explains how innovativeness, proactiveness, and risk-taking enhance enterprise performance (Alnoor et al., 2024; Bouguerra et al., 2023; Gali et al., 2024), while the Sustainable Livelihood Framework emphasizes the interaction between livelihood assets, vulnerability contexts, and livelihood outcomes (Fahad et al., 2023; Tabares et al., 2022). Although each perspective contributes valuable insights, these perspectives have rarely been integrated into a unified framework that explains how institutional support is progressively transformed into livelihood resilience through the sequential development of women's economic agency, entrepreneurial orientation, and market innovation capability. As a result, the capability-building mechanisms underlying resilient livelihood formation remain insufficiently explained (Gomesi et al., 2025; Harper et al., 2020; Ramoni-Perazzi et al., 2026).

Despite the growing body of literature, important methodological limitations remain. Most previous studies have relied on either cross-sectional surveys or qualitative case studies, providing only a partial understanding of both the historical evolution of women's economic roles and the mechanisms through which institutional support contributes to livelihood resilience. This study aims to develop and validate a sequential capability-building model explaining how institutional support contributes to livelihood resilience among women operating household-

based smoked fish enterprises in Indonesia. Building upon these empirical, theoretical, and methodological gaps, this study reconstructs the historical transformation of women's economic agency in household-based smoked fish enterprises between 2014 and 2024 and subsequently validates a sequential capability-building model linking Institutional Support, Women's Economic Agency, Entrepreneurial Orientation, Market Innovation Capability, and Livelihood Resilience using Partial Least Squares Structural Equation Modeling (PLS-SEM). By integrating historical inquiry with quantitative model validation through a mixed-methods sequential exploratory design, this study offers a more comprehensive explanation of how institutional transformation progressively translates into resilient livelihood outcomes. The findings offer both methodological and practical contributions by providing an evidence-based framework to support integrated institutional, entrepreneurial, and market development strategies for strengthening the long-term resilience of women-led small-scale fisheries enterprises.

METHODOLOGY

This study employed a mixed-methods sequential exploratory design, integrating historical inquiry with quantitative model validation, to examine the development of women's economic agency and its relationship to livelihood resilience in household-based smoked fish enterprises in Tegalsari, Tegal City, Central Java, Indonesia. The research was conducted

in two sequential phases. Phase I (Historical Inquiry) reconstructed the evolution of women's economic roles and enterprise conditions between 2014 and 2024 using the classical historical research process of heuristic, verification, interpretation, and historiography (Pike et al., 2024; Stacey et al., 2021). This phase established the historical and contextual foundation for understanding changes in institutional support, women's economic participation, entrepreneurial practices, market adaptation, and livelihood conditions over the study period. The historical evidence was subsequently organized into four analytically distinct periods: 2014–2016, 2017–2019, 2020–2021, and 2022–2024, based on documented changes in institutional arrangements, women's economic roles, enterprise practices, market conditions, and major contextual developments rather than on arbitrary chronological divisions. Phase II (Quantitative Validation) used the contextual insights generated from the historical inquiry to examine the proposed capability-building relationships through Partial Least Squares Structural Equation Modeling (PLS-SEM) (Cheng, 2023; Hair et al., 2021). This sequential design enabled the study to connect the historical transformation of women's economic roles with empirically tested relationships among institutional support, economic agency, entrepreneurial orientation, market innovation capability, and livelihood resilience.

Table 1 presents the integrated research design linking the historical inquiry and quantitative validation phases.

Table 1. Integrated research design and methodological framework

Research component	Purpose / theoretical basis	Main procedures and data	Expected output
Theoretical foundations	The study integrates Institutional Theory (Fauzi & Sheng, 2022; Khattak et al., 2021), Women's Economic Agency Theory (Hing et al., 2022; Rodriguez-Satizabal et al., 2025), Entrepreneurial Orientation Theory (Alnoor et al., 2024; Bouguerra et al., 2023; Gali et al., 2024), Innovation Capability Literature (Goni & Van Looy, 2022; Mendoza-Silva, 2020), and the Sustainable Livelihood Framework (Fahad et al., 2023; Tabares et al., 2022).	The theoretical perspectives are integrated to explain the relationships among institutional support, women's economic agency, entrepreneurial orientation, innovation capability, and livelihood resilience.	Conceptual basis for the historical inquiry and subsequent empirical model.

SOCIAL POLICY AND QUALITY OF LIFE

Phase I. Historical inquiry (2014-2024): Heuristic	Reconstruct the historical evolution of women's economic roles in household-based smoked fish enterprises.	Systematic collection of historical evidence from archives, official documents, statistics, community records, and oral histories.	Initial historical evidence base.
Phase I. Verification	Assess the reliability and credibility of historical evidence.	Source criticism and evaluation; assessment of authenticity, credibility, consistency, and relevance; triangulation across multiple sources.	Verified historical evidence.
Phase I. Interpretation	Identify changes in institutional support, women's roles, entrepreneurial practices, market conditions, and livelihood outcomes.	Interpretation of historical patterns and identification of causal sequences and turning points.	Explanation of the evolution of women's economic activities and their institutional context.
Phase I. Historiography	Develop a coherent historical interpretation of the observed changes.	Synthesis of verified evidence into a historical narrative; periodization into 2014-2016, 2017-2019, 2020-2021, and 2022-2024.	Contextual understanding of the evolution of women-led enterprises.
Historical evidence base	Provide empirical support for Phase I.	40 documentary sources and 20 oral-history interviews. Informants included women smoked fish processors (12), community/cooperative leaders (3), fisheries officials (3), and MSME officials (2).	Triangulated qualitative and historical evidence.
Contextualized conceptual model and instrument development	Translate historical findings into empirically testable constructs and indicators.	Historical insights are used to contextualize constructs, refine measurement items, and develop the survey questionnaire.	Context-specific conceptual model and quantitative research instrument.
Phase II. Instrument development	Ensure measurement validity and contextual relevance.	Items adapted from validated scales and refined through expert review and a pilot test (n = 30).	Final survey instrument.
Phase II. Data collection	Empirically test the proposed model.	Cross-sectional survey using purposive sampling of eligible women entrepreneurs in Tegalsari, Tegal City. Valid responses: 368.	Quantitative dataset for model estimation.
Phase II. PLS-SEM analysis	Assess the measurement properties and test the proposed structural relationships.	Measurement model assessment, structural model assessment, and hypothesis testing, including direct and indirect effects.	Estimates of structural relationships and mediation effects.
Phase II. Quantitative validation	Validate the conceptual model derived from the historical inquiry.	Evaluation of relationships among Institutional Support, Women's Economic Agency, Entrepreneurial Orientation, Market Innovation Capability, and Livelihood Resilience.	Empirically validated model explaining sequential capability-building relationships.
Integrated research design	Link historical context with quantitative hypothesis testing.	Historical Inquiry -> Contextualized Conceptual Model & Instrument Development -> Quantitative Validation (PLS-SEM).	Integrated mixed-stage research framework combining contextual explanation and empirical validation.

Note: compiled by the authors

The study involved two complementary phases of evidence selection and participant recruitment corresponding to the mixed-method sequential exploratory design. In Phase I (Historical Inquiry), the authors purposively selected historical evidence covering 2014–2024 from 40 documentary sources and 20 oral-history interviews. The documentary sources comprised 8 fisheries statistics and production reports, 8 municipal and government records, 7 fisheries and MSME policy documents, 6 MSME development reports, 5 local administrative records, and 6 community or cooperative records. These sources were selected based on their temporal coverage of the study period, institutional provenance, relevance to household-based smoked fish enterprises, and ability to provide evidence of changes in institutional conditions, women's economic roles, entrepreneurial practices, market development, and livelihood conditions. The oral-history component included 20 purposively selected informants: 12 women smoked fish processors, 3 community or cooperative leaders, 3 fisheries officials, and 2 MSME officials. Informants were selected based on their direct involvement in smoked fish processing, institutional responsibility for fisheries or enterprise development, or long-term

knowledge of socio-economic changes in the study area during 2014–2024.

In Phase II (Quantitative Validation), the target population comprised women engaged in household-based smoked fish processing enterprises in Tegalsari, Tegal City, Central Java, Indonesia. The quantitative survey was conducted from May to July 2026. Researchers recruited potential participants through direct identification and contact with eligible household-based smoked fish processors, supported by local fisheries and MSME networks and community contacts. Because no comprehensive sampling frame existed for this specialized population, the study used criterion-based purposive sampling.

A total of 400 questionnaires were distributed to potential participants during the survey period, of which 390 were returned. After screening, 12 questionnaires were excluded due to missing or incomplete responses, and 10 were excluded because they did not meet the predefined eligibility criteria. Consequently, 368 valid questionnaires were retained for the final analysis, representing 92.0% of all questionnaires distributed.

Table 1 presents the demographic characteristics of the final 368 respondents.

Table 1. Demographic characteristics of respondents

Characteristics	Category	N	%	Characteristics	Category	N	%
Age	20–29 years	48	13.04%	Business ownership status	Owner	143	38.86%
	30–39 years	125	33.97%		Co-owner (family business)	116	31.52%
	40–49 years	124	33.70%		Worker/processor	109	29.62%
	≥50	71	19.29%	Participation in government training	Never	91	24.73%
Education level	Primary school	82	22.28%		Once	103	27.99%
	JHS	109	29.62%		2–3 times	111	30.16%
	SHS	132	35.87%		>3times	63	17.12%
	Diploma/Bachelor	45	12.23%	Digital marketing usage	Never	67	18.21%
Business experience	<5 years	57	15.49%		Occasionally	119	32.34%
	5–10 years	118	32.07%		Frequently	131	35.60%
	>10 years	193	52.45%		Very frequently	51	13.86%

Note: compiled by the authors

The authors developed the quantitative instrument during Phase II by integrating insights from the historical inquiry with measurement scales established in previous empirical studies. The historical findings contextualized the measurement items so the instrument reflected the institutional conditions, women's economic roles, entrepreneurial practices, market adaptations, and

livelihood conditions identified in household-based smoked fish enterprises. Measurement items were adapted from previously validated scales while retaining their original conceptual meaning to ensure theoretical consistency and content validity.

Three experts in entrepreneurship, fisheries economics, and quantitative research reviewed the preliminary questionnaire to assess the clarity,

relevance, and contextual appropriateness of the items. A pilot study involving 30 women engaged in smoked fish processing was then conducted to identify ambiguous wording and improve the questionnaire's readability and contextual suitability before the main survey. All constructs were measured using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The final instrument comprised five latent constructs:

Institutional Support, Women's Economic Agency, Entrepreneurial Orientation, Market Innovation Capability, and Livelihood Resilience. Their dimensions and indicators were adapted from established literature and refined to reflect the historical and contemporary context of women-led household-based smoked fish enterprises. Table 2 presents the measurement dimensions, indicator codes, and supporting references.

Table 2. Measurement constructs for coastal women's fisheries enterprises

Construct	Dimension	Item	References
Institutional Support (INS)	Training Support, Financial Support, Market Support, Information Support, Regulatory Support	INS1–INS5	(Chambon et al., 2024; Freeman & Svets, 2022; Macusi et al., 2023)
Women's Economic Agency (WEA)	Decision-making, Resource Control, Entrepreneurial Autonomy, Business Participation, Future Orientation	WEA1–WEA5	(Hing et al., 2022; Pedroza-Gutiérrez et al., 2024; Rodríguez-Satizábal et al., 2025).
Entrepreneurial Orientation (ENO)	Innovativeness, Proactiveness, Risk-taking, Opportunity Seeking	ENO1–ENO4	(Alnoor et al., 2024; Bouguerra et al., 2023; Gali et al., 2024)
Market Innovation Capability (MIC)	Product Innovation, Branding, Digital Marketing, Customer Engagement, Market Adaptation	MIC1–MIC5	(Goni & Van Looy, 2022; Mendoza-Silva, 2020)
Livelihood Resilience (LR)	Adaptive Capacity, Income Stability, Economic Recovery, Resource Flexibility, Business Continuity	LR1–LR5	(Fabinyi et al., 2022; Fahad et al., 2023; Tabares et al., 2022).

Note: compiled by the authors

Data analysis followed the two sequential phases of the research design. In Phase I (Historical Inquiry), the researchers analyzed documentary and oral-history evidence using the classical historical research procedure of heuristic, verification, interpretation, and historiography (Pike et al., 2024; Stacey et al., 2021). Documentary evidence was organized chronologically and thematically according to institutional conditions, women's economic roles, entrepreneurial practices, market adaptation, and livelihood changes. Oral-history interviews were transcribed and coded thematically, after which recurring accounts were compared across informant groups and cross-checked against documentary evidence to identify convergent and divergent evidence. Source verification considered the provenance, temporal relevance, consistency, and corroboration of available evidence, while discrepancies were examined by comparing it with other documentary and oral-history sources. This interpretive process identified four historical periods—2014–2016, 2017–2019, 2020–2021, and 2022–2024—based on converging evidence

of substantive changes across these dimensions rather than predetermined chronological divisions. The resulting historical narrative provided the contextual foundation for the quantitative model and informed the contextualization of the measurement instrument.

In Phase II (Quantitative Validation), the survey data were analyzed using SmartPLS 4 following the PLS-SEM procedures (Al-Fraihat et al., 2020; Daryono et al., 2024; Sarstedt et al., 2020). The analysis comprised two stages. First, the measurement model was evaluated for indicator reliability, internal consistency reliability, convergent validity, and discriminant validity using outer loadings, Cronbach's alpha, composite reliability (CR), average variance extracted (AVE), and the heterotrait–monotrait ratio (HTMT). Second, the structural model was assessed through collinearity, path coefficients, coefficients of determination (R^2), effect sizes (f^2), predictive relevance (Q^2), and standardized root mean square residual (SRMR). Hypothesis testing examined the proposed direct and indirect relationships to

determine the sequential mechanisms linking institutional support with livelihood resilience. This analytical sequence enabled the study to integrate historically reconstructed transformations with empirical evidence on the proposed capability-building relationships.

RESULTS

The historical inquiry reconstructed the evolution of women's economic agency in household-based smoked fish enterprises in Tegalsari, Tegal City, Central Java, from 2014 to 2024. The study examined documentary and oral-history evidence across changes in institutional conditions, women's participation in enterprise activities, entrepreneurial practices, market adaptation, and livelihood

conditions. The evidence was not treated as a series of isolated events; instead, recurring changes across documentary records and oral-history accounts were compared and interpreted to identify periods when women's economic roles and enterprise practices underwent substantive transformation. This process produced four historically distinct phases: 2014–2016, 2017–2019, 2020–2021, and 2022–2024. The periodization reflects the convergence of changes in institutional engagement, women's participation in decision-making, enterprise development, market adaptation, and broader contextual conditions.

As shown in Figure 2, women's economic roles evolved progressively from traditional processing activities toward entrepreneurial participation, market innovation, and stronger livelihood resilience between 2014 and 2024.

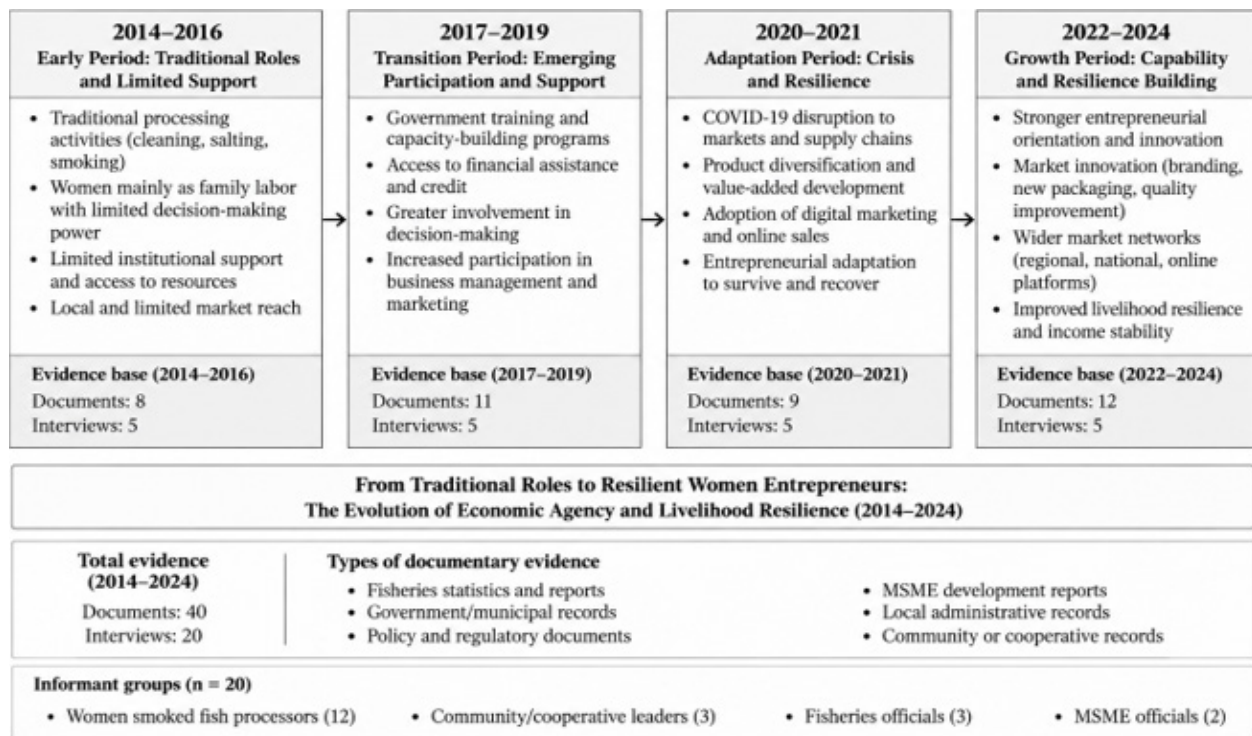


Figure 2. Evolution of women's economic agency and livelihood resilience for 2014–2024

During 2014–2016, women's economic participation was primarily concentrated in processing and other routine production activities. The available evidence indicates relatively limited institutional engagement and market facilitation, which constrained opportunities for women to participate in broader enterprise management and strategic decision-making. Their contribution remained economically important to household

production and income maintenance, but their role was predominantly operational rather than managerial. This period therefore represents the initial production-oriented stage of the historical trajectory, providing the baseline against which subsequent changes in women's economic agency can be understood.

The 2017–2019 period marked a transition toward greater institutional engagement and

broader economic participation. Documentary evidence concerning training, financial assistance, business facilitation, and enterprise development, together with oral-history accounts, indicates that women increasingly participated in production planning, financial management, and marketing activities. The expansion of these roles suggests that institutional engagement was associated with greater opportunities for women to exercise economic decision-making beyond routine processing. Entrepreneurial practices also began to develop as women became more involved in managing and expanding household enterprises. This period is therefore interpreted as an institutional engagement stage, in which women's economic agency became more visible within enterprise decision-making and business development.

A distinct transformation occurred during 2020–2021, when the COVID-19 pandemic disrupted established market and enterprise conditions. Rather than maintaining previous operating practices unchanged, women increasingly responded through product diversification, alternative marketing practices, and the development of new customer connections. The oral histories and documentary evidence indicate that these responses reflected a shift toward more active adaptation to external

market disruption. Women's roles consequently became increasingly connected with entrepreneurial problem-solving and business continuity rather than being limited to production activities. This period is therefore characterized as a crisis-adaptation stage, in which disruption accelerated the development of entrepreneurial responses and adaptive enterprise practices.

During 2022–2024, the historical trajectory moved toward stronger market-oriented and strategic roles. Evidence indicates increasing involvement in enterprise management, alongside greater attention to branding, digital marketing, market innovation, and broader market linkages. Importantly, these practices can be interpreted as a continuation and consolidation of capabilities developed during the preceding period rather than as an entirely new transformation. Women's economic agency increasingly involved decisions concerning market positioning, customer engagement, and enterprise development, while improved business continuity contributed to more resilient livelihood conditions. This period therefore represents the market-oriented capability stage of the historical trajectory.

Table 3 summarizes the evidence base and interpretation underlying the four historical phases.

Table 3. Historical phases and evidence of women's economic transformation in household-based smoked fish enterprises for 2014–2024

Historical phase	Institutional context	Women's economic role	Entrepreneurial/market development	Evidence base	Historical interpretation
2014–2016	Relatively limited institutional engagement and market facilitation	Predominantly involved in processing and routine production activities	Limited entrepreneurial and market-oriented practices	Fisheries statistics and production reports; municipal and local administrative records; community/cooperative records; oral-history accounts from women processors and community/cooperative leaders	Initial production-oriented stage, with women's economic contribution concentrated primarily at the operational level
2017–2019	Increasing training, financial assistance, and business facilitation	Greater participation in production planning, financial management, and marketing	Emerging entrepreneurial practices and broader market participation	Fisheries and MSME policy documents; MSME development reports; municipal/government records; fisheries statistics; oral-history accounts from women processors, community/cooperative leaders, fisheries officials, and MSME officials	Institutional engagement stage, characterized by expanding economic agency and participation in enterprise management

2020–2021	Pandemic-related disruption and changing institutional and market conditions	Increasing involvement in adaptive business decisions	Product diversification, alternative marketing practices, and development of new customer connections	Fisheries statistics and production reports; government and municipal records; MSME reports; relevant policy documents; oral-history accounts from women processors, community/cooperative leaders, and relevant officials	Crisis-adaptation stage, in which external disruption stimulated stronger entrepreneurial responses and adaptive business practices
2022–2024	Increasing market facilitation, digitalization, and enterprise development support	Greater involvement in enterprise management and strategic decision-making	Branding, digital marketing, market innovation, and broader market linkages	MSME development reports; fisheries and MSME policy documents; municipal/government records; community/cooperative records; oral-history accounts from women processors, community/cooperative leaders, fisheries officials, and MSME officials	Market-oriented capability stage, characterized by stronger entrepreneurial and market capabilities associated with improved business continuity and livelihood resilience

Note: compiled by the authors

Taken together, the four periods demonstrate a cumulative transformation of women's economic agency from predominantly production-oriented participation toward decision-making, entrepreneurial engagement, and market-oriented enterprise management. The historical evidence suggests that this transformation occurred through successive changes in institutional conditions and enterprise practices rather than through a single intervention or abrupt organizational shift. The trajectory also provides important context for the relationships examined in the subsequent quantitative phase: institutional engagement created conditions for broader economic participation,

while entrepreneurial adaptation and market-oriented practices became increasingly prominent as women responded to changing enterprise conditions. However, this historical reconstruction does not establish causal relationships among these capabilities; rather, it provides the empirical and temporal context for the structural relationships subsequently tested using PLS-SEM.

As illustrated in Figure 3, all measurement indicators exhibited standardized outer loadings exceeding the recommended threshold of 0.70, confirming that each indicator adequately represented its corresponding latent construct.

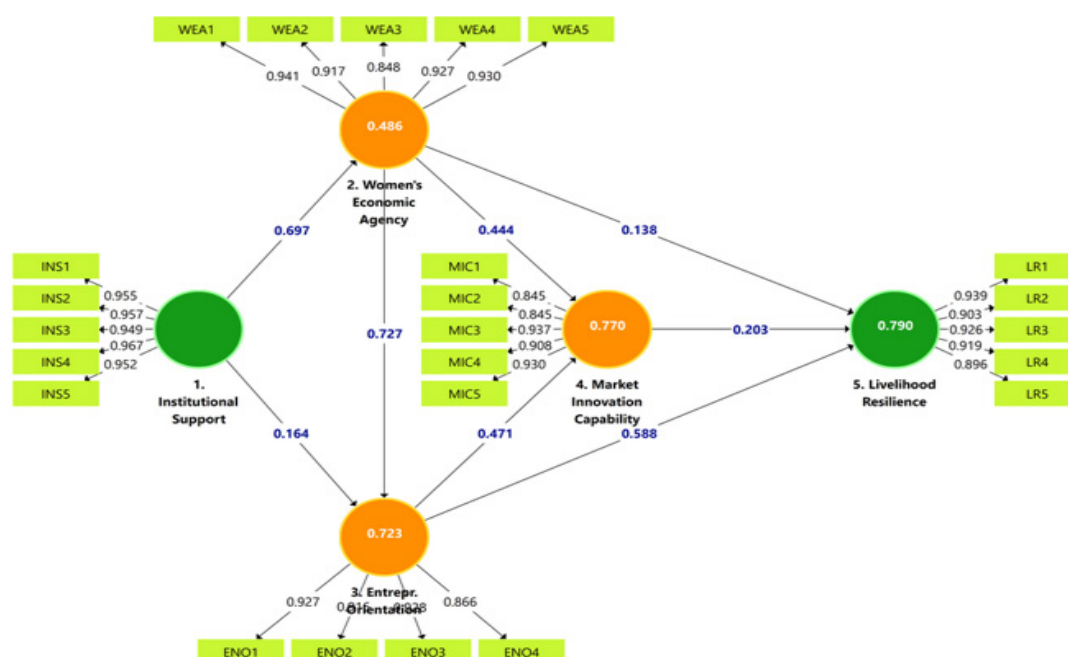


Figure 3. Proposed structural model of livelihood resilience among women in small-scale smoked fish enterprises

The highest outer loading was observed for INS4 under the Institutional Support construct ($\lambda = 0.967$), indicating that this indicator best represented institutional support perceived by women engaged in smoked fish processing enterprises. Conversely, MIC1 had the lowest loading within the Market Innovation Capability construct ($\lambda = 0.845$). Nevertheless, this value remained substantially

above the acceptable criterion, indicating satisfactory indicator reliability across all five constructs.

Discriminant validity was assessed using the Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT), as recommended by Hair and Alamer (2022). Table 4 presents the results of the discriminant validity assessment.

Table 4. Discriminant validity assessment using the fornell–larcker criterion and HTMT ratio

Constructs	INS	WEA	ENO	MIC	LR
INS	0.956	0.537	0.523	0.497	0.549
WEA	0.697	0.913	0.771	0.768	0.727
ENO	0.672	0.842	0.910	0.779	0.799
MIC	0.639	0.840	0.844	0.894	0.743
LR	0.615	0.803	0.875	0.815	0.917

Note: compiled by the authors

Discriminant validity was assessed using the combined Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT), as recommended by Hair and Alamer (2022). As presented in Table 4, the square root of the Average Variance Extracted (AVE) for each construct, reported on the diagonal, was consistently greater than the corresponding inter-construct correlations reported below the diagonal, thereby satisfying the Fornell–Larcker criterion and confirming adequate discriminant validity. Furthermore, all HTMT values reported above the diagonal ranged from

0.497 (Institutional Support–Market Innovation Capability) to 0.799 (Entrepreneurial Orientation–Livelihood Resilience), remaining well below the conservative threshold of 0.85. These findings indicate that each latent construct captured a distinct conceptual domain and was empirically distinguishable from the others, confirming that the proposed measurement model possesses satisfactory discriminant validity and is appropriate for subsequent structural model evaluation.

Table 5 presents the structural model's explanatory power, effect sizes, and predictive relevance.

Table 5. Explanatory power, effect size, and predictive relevance of the structural model

Endogenous	Power		Effect size			Predictive	
	R ²	Interpretation	Exogenous	f ²	Size	Q ²	Interpretation
WEA	0.486	Moderate	INS	0.945	Large	0.398	Large
ENO	0.723	Substantial	INS	0.050	Small	0.592	Large
			WEA	0.981	Large		
MIC	0.770	Substantial	WEA	0.250	Medium	0.611	Large
			ENO	0.281	Medium		
LR	0.790	Substantial	WEA	0.021	Small	0.656	Large
			ENO	0.374	Large		
			MIC	0.045	Small		

Note: compiled by the authors

As presented in Table 5, the model demonstrated moderate explanatory power for Women's Economic Agency ($R^2 = 0.486$) and substantial explanatory power for Entrepreneurial Orientation ($R^2 = 0.723$), Market Innovation Capability ($R^2 = 0.770$), and Livelihood Resilience ($R^2 = 0.790$), indicating that the proposed model effectively explains the formation of livelihood resilience among women in small-scale smoked fish enterprises. The effect size analysis further revealed that Institutional Support exerted a large effect on Women's Economic Agency ($f^2 = 0.945$), Women's Economic Agency had a large effect on Entrepreneurial Orientation ($f^2 = 0.981$), while Entrepreneurial Orientation produced a large effect on Livelihood Resilience ($f^2 = 0.374$), whereas the remaining direct relationships exhibited small to medium effect sizes. Furthermore, all endogenous constructs produced positive Q^2 values

ranging from 0.398 to 0.656, substantially exceeding the recommended threshold of zero and indicating strong predictive relevance of the proposed model. Among the endogenous constructs, Livelihood Resilience achieved the highest predictive relevance ($Q^2 = 0.656$), suggesting that the sequential relationships among Institutional Support, Women's Economic Agency, Entrepreneurial Orientation, and Market Innovation Capability provide substantial predictive capability in explaining livelihood resilience. Overall, these findings confirm that the structural model possesses satisfactory explanatory power, meaningful effect sizes, and strong predictive relevance for understanding livelihood resilience among women engaged in small-scale fisheries.

The significance of the hypothesized direct relationships was evaluated using the bootstrapping procedure, and the results are presented in Table 6.

Table 6. Direct and indirect effects of the proposed structural model

Hypothesis	Structural Path	β_{value}	t_{value}	p_{value}	Effect strength	Decision
H1	INS $\rightarrow$ WEA	0.697	14.990	<0.001	Strong	Supported
H2	INS $\rightarrow$ ENO	0.164	2.792	0.005	Weak	Supported
H3	WEA $\rightarrow$ ENO	0.727	14.212	<0.001	Strong	Supported
H4	WEA $\rightarrow$ 4. MIC	0.444	7.094	<0.001	Moderate	Supported
H5	WEA $\rightarrow$ LR	0.138	1.446	0.149	Weak	Not supported
H6	ENO $\rightarrow$ 4. MIC	0.471	7.116	<0.001	Moderate	Supported
H7	ENO $\rightarrow$ LR	0.588	7.591	<0.001	Strong	Supported
H8	MIC $\rightarrow$ LR	0.203	2.851	0.005	Weak	Supported
H-M1	INS $\rightarrow$ WEA $\rightarrow$ ENO $\rightarrow$ LR	0.298	5.870	<0.001	Significant sequential	Supported
H-M2	INS $\rightarrow$ WEA $\rightarrow$ LR	0.096	1.424	0.155	Not significant	Not supported
H-M3	INS $\rightarrow$ ENO $\rightarrow$ MIC $\rightarrow$ LR	0.016	1.832	0.068	Not significant	Not supported
H-M4	WEA $\rightarrow$ ENO $\rightarrow$ LR	0.427	6.210	<0.001	Significant	Supported
H-M5	ENO $\rightarrow$ MIC $\rightarrow$ LR	0.095	2.575	0.010	Significant partial	Supported

Note: compiled by the authors

Seven of the eight direct hypotheses were supported, indicating that Institutional Support significantly enhanced Women's Economic

Agency and Entrepreneurial Orientation, while Women's Economic Agency positively influenced Entrepreneurial Orientation and Market Innovation

Capability. Entrepreneurial Orientation also had significant positive effects on both Market Innovation Capability and Livelihood Resilience, and Market Innovation Capability also contributed significantly to Livelihood Resilience. However, the direct relationship between Women's Economic Agency and Livelihood Resilience (H5) was not statistically significant ($\beta = 0.138$, $p = 0.149$), indicating that women's economic agency alone was insufficient to directly strengthen livelihood resilience. These findings suggest that women's economic agency contributes primarily through other strategic capabilities rather than directly.

The indirect effect analysis revealed that the proposed mediation pathways contributed differently to the structural model. As presented in Table 6, significant indirect effects were identified for Institutional Support $\rightarrow$ Women's Economic Agency $\rightarrow$ Entrepreneurial Orientation $\rightarrow$ Livelihood Resilience (H-M1), Women's Economic Agency $\rightarrow$ Entrepreneurial Orientation $\rightarrow$ Livelihood Resilience (H-M4), and Entrepreneurial Orientation $\rightarrow$ Market Innovation Capability $\rightarrow$ Livelihood Resilience (H-M5), whereas the mediation pathways through Women's Economic Agency alone (H-M2) and through Entrepreneurial Orientation and Market Innovation Capability without Women's Economic Agency (H-M3) were not statistically significant. Among the significant mediation effects, the pathway from Women's Economic Agency through Entrepreneurial Orientation to Livelihood Resilience (H-M4) showed the largest indirect effect ($\beta = 0.427$), indicating that Entrepreneurial Orientation is the dominant capability through which women's economic agency translates into sustainable livelihood outcomes. These findings demonstrate that entrepreneurial capability, rather than economic agency alone, constitutes the principal mechanism underlying livelihood resilience among women engaged in household-based smoked fish enterprises. Figure 4 shows the overall structural mechanism underlying the proposed sequential capability-building process, including the significant and non-significant direct and indirect pathways leading to Livelihood Resilience. The figure highlights the progression from Institutional Support through Women's Economic Agency and Entrepreneurial Orientation toward Market Innovation Capability and ultimately Livelihood Resilience, while also distinguishing the supporting mediation pathways

and the non-significant direct relationship between Women's Economic Agency and Livelihood Resilience.

DISCUSSION

The findings show that Institutional Support is a key catalyst for strengthening Women's Economic Agency among women engaged in household-based smoked fish enterprises. Institutional interventions, including entrepreneurial training, financial assistance, market facilitation, information access, and regulatory support, create enabling conditions for women to participate more actively in business decision-making, control productive resources, and engage in enterprise management. From the perspective of Institutional Theory, such support reduces structural barriers and facilitates access to economic opportunities (Fauzi & Sheng, 2022; Khattak et al., 2021). The present finding is consistent with previous studies showing that institutional support strengthens women's economic participation and empowerment in fisheries and other coastal livelihood sectors (Chambon et al., 2024; Freeman & Svendsen, 2022; Harper et al., 2020). These findings suggest that institutional support functions not merely as an external resource provider but as a strategic enabler that facilitates women's transition from passive participants to active economic actors within small-scale fisheries enterprises.

A central finding of this study is that Women's Economic Agency did not directly enhance Livelihood Resilience but exerted its strongest influence through Entrepreneurial Orientation. Women's decision-making authority, control over productive resources, entrepreneurial autonomy, and active participation in household enterprises therefore appear insufficient to strengthen livelihood resilience unless they are translated into entrepreneurial behaviours such as innovativeness, proactiveness, opportunity seeking, and calculated risk-taking. This finding differs partly from previous studies that reported a more direct positive relationship between women's economic empowerment and livelihood resilience (Fabinyi et al., 2022; Malhotra et al., 2024; Rodríguez-Satizábal et al., 2025), suggesting that empowerment itself is often considered sufficient to improve household welfare. At the same time, it is consistent with research showing that entrepreneurial orientation

enhances the adaptability, competitiveness, and resilience of micro and small enterprises under uncertain economic conditions (Alnoor et al., 2024; Bouguerra et al., 2023; Gali et al., 2024).

The findings reveal that Market Innovation Capability functions as a strategic capability that strengthens the contribution of Entrepreneurial Orientation to Livelihood Resilience among women operating household-based smoked fish enterprises. Women with stronger entrepreneurial orientation were more likely to introduce product innovations, develop distinctive branding strategies, adopt digital marketing practices, strengthen customer engagement, and adapt to changing market conditions, thereby improving the sustainability of their businesses and household livelihoods. This finding is consistent with previous studies reporting that innovation capability enhances the competitiveness, adaptability, and long-term sustainability of small-scale enterprises operating under dynamic market conditions (Goni & Van Looy, 2022; Mendoza-Silva, 2020). Similarly, recent studies have emphasized that market-oriented innovation enables fisheries enterprises to respond more effectively to changing consumer preferences, technological developments, and economic uncertainty (Ramoni-Perazzi et al., 2026; Stacey et al., 2021). These findings indicate that innovation capability plays a crucial role in enabling women-led fisheries enterprises to transform entrepreneurial initiatives into adaptive market responses that support sustainable livelihood outcomes.

Despite its significant contribution, the direct effect of Market Innovation Capability on Livelihood Resilience was weaker than that of Entrepreneurial Orientation, suggesting that innovation alone is insufficient to sustain resilient livelihoods without a strong entrepreneurial foundation. This finding implies that the success of innovation depends on entrepreneurs' ability to recognize opportunities, proactively respond to market changes, and mobilize available resources to implement innovative business strategies. Rather than functioning as an independent driver, Market Innovation Capability complements Entrepreneurial Orientation by facilitating the commercialization of entrepreneurial ideas through product differentiation, branding, digital marketing, and market adaptation. Consequently, this study extends the innovation capability literature by positioning

Market Innovation Capability as a complementary capability within a broader sequential capability-building process, where innovation reinforces, but does not replace the central role of Entrepreneurial Orientation in strengthening livelihood resilience among women-led small-scale fisheries enterprises.

This study contributes to the literature by integrating Institutional Theory, Women's Economic Agency Theory, Entrepreneurial Orientation Theory, and the Sustainable Livelihood Framework into a unified capability-building model for women-led small-scale fisheries enterprises. While previous studies have generally examined institutional support, women's empowerment, entrepreneurship, or livelihood resilience as separate determinants, this study shows that these constructs operate through a sequential, interdependent process. In particular, the findings extend Women's Economic Agency Theory by showing that economic agency alone does not directly strengthen livelihood resilience; rather, its influence is realized through the development of entrepreneurial orientation and supported by market innovation capability. This sequential mechanism advances the Sustainable Livelihood Framework by positioning entrepreneurial capability as the key intermediary that transforms institutional resources and women's economic agency into resilient livelihood outcomes. Accordingly, the study provides a more comprehensive theoretical explanation of how capability development, rather than isolated resource provision, underpins livelihood resilience in women-led small-scale fisheries.

The findings offer several practical implications for policymakers and development agencies seeking to strengthen the sustainability of women-led fisheries enterprises. Government interventions should move beyond conventional financial assistance and technical training by adopting integrated programs that simultaneously enhance women's economic agency, entrepreneurial orientation, and market innovation capability. Capacity-building initiatives should prioritize entrepreneurial mentoring, business incubation, digital marketing adoption, product diversification, and market networking, enabling women processors to transform institutional support into sustainable business growth and resilient livelihoods. Furthermore, fisheries cooperatives, MSME development agencies, and local governments should collaborate to establish innovation-oriented

support systems that facilitate continuous learning, market adaptation, and knowledge exchange among women entrepreneurs. Such integrated policy approaches are expected to improve not only household economic resilience but also the long-term competitiveness and sustainability of small-scale fisheries in coastal communities.

CONCLUSION

This study integrated historical inquiry and Partial Least Squares Structural Equation Modeling (PLS-SEM) to explain how institutional support contributes to livelihood resilience among women engaged in household-based smoked fish enterprises. The historical reconstruction revealed that women's economic roles evolved progressively between 2014 and 2024, shifting from traditional production activities toward entrepreneurial leadership and market-oriented business development. Quantitative analysis confirmed these historical patterns, showing that Institutional Support strengthens Women's Economic Agency, which in turn enhances Entrepreneurial Orientation and Market Innovation Capability before ultimately improving Livelihood Resilience. The findings further indicate that Women's Economic Agency alone does not directly generate livelihood resilience; instead, its contribution is realized through the development of entrepreneurial capability and market innovation. Collectively, these results demonstrate that resilient livelihoods emerge through a sequential capability-building process, in which institutional interventions progressively develop women's entrepreneurial capacities and adaptive market capabilities rather than producing immediate livelihood outcomes.

This study contributes by proposing and empirically validating a sequential capability-building model that integrates historical transformation with contemporary causal relationships, thereby providing a more comprehensive explanation of women's economic development in small-scale fisheries. The findings suggest that policies for women-led fisheries enterprises should move beyond conventional financial assistance by strengthening institutional ecosystems that simultaneously promote women's economic agency, entrepreneurial capability, and market innovation. Such integrated interventions are expected to enhance the long-term resilience,

competitiveness, and sustainability of coastal household enterprises. Although the study provides robust evidence by integrating historical and quantitative approaches, it was conducted within a single smoked fish processing cluster in Indonesia, which may limit the transferability of the findings to other fisheries sectors or regional contexts. Future research is therefore encouraged to validate the proposed capability-building model across different fisheries industries and countries using longitudinal mixed-method designs to better capture how institutional change and entrepreneurial capability co-evolve over time.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: IS and HR; research design: IS, ES and HR; data collection: IS, ES and HR; analysis and interpretation: IS and ES; writing draft preparation: IS, ES and HR; supervision: HR; correction of article: IS, ES and HR; proofread and final approval of article: IS, ES and HR. All authors have read and agreed to the published version of the manuscript.

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Economic Factors Associated with Income Inequality: Panel Evidence from 93 Countries

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ABSTRACT

Income inequality constitutes a significant characteristic of socio-economic development, since an increase in aggregate output is not identical to broader participation of different population groups in the distribution of generated income. The aim of this study is to identify economic factors consistently associated with within-country changes in income inequality using panel data from 93 countries over the period 2002–2021. The empirical analysis is based on data from the World Bank's World Development Indicators and Poverty and Inequality Platform. The sample covers 93 countries over the period 2002–2021 and includes 1,369 country-year observations in an unbalanced panel. The study employs descriptive statistics, correlation analysis, multicollinearity diagnostics, and panel regression analysis. The results indicate a robust negative association between income inequality and the level of economic development: a 1% increase in GDP per capita is associated with an approximately 0.048-point decrease in the Gini index ($p < 0,01$). A one-percentage-point increase in the unemployment rate is associated with a 0.068-point increase in the Gini index ($p < 0,01$), while a 10-percentage-point increase in trade openness is associated with an approximately 0.27-point increase in the Gini index ($p < 0,01$). These relationships remain robust across alternative model specifications and when the models are estimated separately for income-based and consumption-based Gini measures. The estimates for GDP growth, natural resource rents, urbanization, and inflation are less robust. Further research may extend the analysis through dynamic panel models, instrumental-variable approaches, and alternative databases on inequality.

KEYWORDS: Economy, Economic Growth, Trade Openness, Unemployment, Natural Resource Rent, Income Inequality, Foreign Economic Strategy

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Экономические факторы доходного неравенства: панельный анализ данных по 93 странам

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АННОТАЦИЯ

Доходное неравенство представляет собой существенную характеристику социально-экономического развития, поскольку увеличение совокупного выпуска не тождественно расширению участия различных групп населения в распределении создаваемого дохода. Цель исследования — выявить экономические факторы, демонстрирующие устойчивую статистическую связь с изменениями доходного неравенства внутри стран, на основе панельных данных по 93 странам за 2002–2021 гг. Эмпирическую основу исследования составили данные World Development Indicators и Poverty and Inequality Platform Всемирного банка. Выборка охватывает 93 страны за 2002–2021 гг. и включает 1 369 наблюдений типа «страна-год» в рамках несбалансированной панели. В исследовании применены методы описательной статистики, корреляционного анализа, диагностики мультиколлинеарности и панельного регрессионного анализа. Результаты исследования показали устойчивую отрицательную связь доходного неравенства с уровнем экономического развития: увеличение ВВП на душу населения на 1% связано со снижением индекса Джини примерно на 0,048 пункта ($p < 0,01$). Повышение уровня безработицы на 1 процентный пункт соответствует увеличению индекса Джини на 0,068 пункта ($p < 0,01$), а увеличение торговой открытости на 10 процентных пунктов ВВП - росту индекса Джини примерно на 0,27 пункта ($p < 0,01$). Подобные зависимости сохраняются при изменении спецификации модели и раздельном оценивании индекса Джини, рассчитанного по доходам и потреблению. Оценки темпа роста ВВП, природной ренты, урбанизации и инфляции характеризуются меньшей устойчивостью. Дальнейшие исследования целесообразно ориентировать на применение динамических панельных моделей, инструментальных переменных и альтернативных баз данных по неравенству.

КЛЮЧЕВЫЕ СЛОВА: экономика, экономический рост, торговая открытость, безработица, природная рента, доходное неравенство, внешнеэкономическая стратегия

КОНФЛИКТ ИНТЕРЕСОВ: авторы заявляют об отсутствии конфликта интересов

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ВВЕДЕНИЕ

Распределение доходов относится к числу существенных характеристик общественно-экономического развития, поскольку отражает не только достигнутый уровень благосостояния, но и степень участия различных групп населения в результатах экономического роста. Показатели выпуска характеризуют общий масштаб хозяйственной деятельности, тогда как показатели неравенства отражают особенности распределения экономических результатов между различными группами населения. Значимость данной проблемы закреплена в международной повестке устойчивого развития: цель 10 ООН направлена на сокращение неравенства внутри стран и между странами (United Nations, 2026). В докладе World Social Report 2025 подчеркивается, что высокий уровень неравенства, экономическая незащищенность и снижение общественного доверия усиливают риски социального развития и требуют пересмотра подходов к социальной и экономической политике (United Nations Department of Economic and Social Affairs, 2025). В этих условиях эмпирическое изучение факторов, связанных с распределением доходов, сохраняет важное значение для оценки устойчивости экономического развития и его социальных результатов.

В научной литературе доходное неравенство рассматривается во взаимосвязи с уровнем экономического развития, темпами роста, состоянием рынка труда, внешнеэкономическими связями, ресурсной обеспеченностью, институциональными условиями и механизмами перераспределения. Вместе с тем указанные факторы нередко анализируются раздельно либо в пределах отдельных страновых и региональных исследований, что затрудняет сопоставление устойчивости выявляемых взаимосвязей в рамках единой эмпирической модели. Недостаточно изученным остается вопрос о том, какие макроэкономические и структурные характеристики сохраняют статистическую связь с индексом Джини не только в межстрановом сопоставлении, но и при анализе изменений внутри стран во времени.

Научная новизна исследования состоит в комплексной оценке устойчивости внутри-

страновых взаимосвязей между доходным неравенством и совокупностью макроэкономических и структурных характеристик в рамках единой межстрановой панельной модели. Использование модели с фиксированными страновыми эффектами позволяет учитывать устойчивые ненаблюдаемые особенности национальных экономик и оценивать изменения индекса Джини в связи с динамикой рассматриваемых факторов внутри стран во времени. Отдельное внимание уделено разграничению достигнутого уровня экономического развития и краткосрочной динамики выпуска посредством одновременного включения ВВП на душу населения и темпа роста ВВП. Устойчивость полученных оценок проверяется в нескольких спецификациях, включая модель со страновыми фиксированными эффектами, двустороннюю модель со страновыми и годовыми эффектами, нелинейную спецификацию для проверки гипотезы Кузнецца и модель, оцененную на выборке стран с более полными рядами наблюдений. Дополнительная проверка проводится раздельно для показателей Джини, рассчитанных по доходам и потреблению.

На основе теоретических положений и результатов предшествующих эмпирических исследований определены ожидаемые направления связи рассматриваемых экономических факторов с доходным неравенством. Более высокий уровень экономического развития и рост экономической активности могут сопровождаться расширением занятости и увеличением трудовых доходов, создавая предпосылки для снижения неравенства. Повышение безработицы, напротив, ограничивает доступ населения к трудовым доходам. Ожидаемая положительная связь торговой открытости с индексом Джини обусловлена возможной неравномерностью распределения выгод и адаптационных издержек внешнеэкономической интеграции. Предполагаемая положительная связь природной ренты с индексом Джини объясняется возможной концентрацией рентных доходов, тогда как ожидаемая отрицательная связь урбанизации обусловлена расширением доступа населения к занятости, инфраструктуре и социальным услугам. Положительная связь инфляции с неравенством предполагается вследствие ее неодинакового воздействия

на покупательную способность различных групп населения, прежде всего домохозяйств с низкими и фиксированными доходами.

Цель исследования состоит в выявлении макроэкономических и структурных характеристик, сохраняющих устойчивую статистическую связь с индексом Джини при анализе внутривнутристрановых изменений на основе панельных данных по 93 странам за 2002–2021 гг. Для достижения поставленной цели оценивается связь индекса Джини с ВВП на душу населения по ППС, темпами экономического роста, безработицей, торговой открытостью, природной рентой, урбанизацией и инфляцией. На этой основе сформулированы следующие исследовательские гипотезы:

H1. Уровень ВВП на душу населения отрицательно связан с индексом Джини.

H2. Темп роста ВВП отрицательно связан с индексом Джини.

H3. Уровень безработицы положительно связан с индексом Джини.

H4. Торговая открытость положительно связана с индексом Джини.

H5. Доля природной ренты в ВВП положительно связана с индексом Джини.

H6. Уровень урбанизации отрицательно связан с индексом Джини.

H7. Уровень инфляции положительно связан с индексом Джини.

ЛИТЕРАТУРНЫЙ ОБЗОР

Проблема распределения доходов относится к числу основных вопросов экономической науки, поскольку она связана с характером экономического роста, развитием производства, состоянием рынка труда, внешнеэкономическими связями, использованием природных ресурсов и деятельностью государственных институтов. В отличие от бедности, которая характеризует недостаточность средств у определенной части населения, неравенство отражает степень различий в распределении экономического благосостояния между группами населения. В связи с этим индекс Джини широко применяется в межстрановых исследованиях, хотя его аналитические возможности ограничены: данный показатель выражает общий уровень неравномерности распределения доходов, но

не раскрывает, за счет каких групп населения происходят его изменения. Следовательно, изучение доходного неравенства требует рассмотрения не только среднего уровня доходов, но и тех экономических условий, при которых рост производства, занятость, торговая открытость, ресурсная обеспеченность и макроэкономическая устойчивость связаны с изменением распределения доходов.

Классическая постановка данной проблемы восходит к работе Кузнецца, в которой была выдвинута гипотеза о нелинейной связи между экономическим развитием и доходным неравенством (Kuznets, 1955). Согласно этой гипотезе, на ранних этапах индустриализации неравенство может возрасти вследствие перемещения рабочей силы из традиционного сектора в современный, различий в производительности труда и сосредоточения доходов в более развитых отраслях. На последующих этапах развития неравенство может снижаться под влиянием расширения образования, роста занятости в городском секторе, развития социальной политики и перераспределительных механизмов. Вместе с тем последующие исследования показали, что указанная зависимость не является универсальной. Ее выявление зависит от состава стран, периода наблюдения, качества статистических данных и выбора эконометрической модели. Поэтому значение гипотезы Кузнецца для настоящего исследования состоит не в признании единой закономерности для всех стран, а в необходимости проверки как линейной, так и нелинейной связи между уровнем экономического развития и доходным неравенством.

Дальнейшее развитие теории показало, что распределение доходов нельзя объяснить только средним уровнем производства или дохода на душу населения. В работе Галора и Зейры (Galor & Zeira, 1993) неравенство рассматривается через ограничения доступа к образованию, кредиту и накоплению человеческого капитала. Алезина и Родрик (Alesina & Rodrik, 1994), а также Перссон и Табеллини (Persson & Tabellini, 1994) связывают распределение доходов с политико-экономическими механизмами налогообложения, перераспределения и инвестиционного поведения. В этих работах неравенство выступает не только следствием

экономического развития, но и фактором, который может воздействовать на его дальнейшее направление через различия в доступе к ресурсам, образованию, капиталу и государственным решениям.

В современной литературе доходное неравенство рассматривается как результат взаимодействия производства, труда, капитала и институтов. Аткинсон подчеркивает значение занятости, налогов, трансфертов и социальной политики в регулировании распределительных процессов (Atkinson, 2015). Пикетти анализирует долгосрочные причины концентрации доходов и богатства (Piketty, 2014). Миланович показывает, что различия в доходах складываются не только внутри отдельных стран, но и между странами (Milanovic, 2016). Стиглиц связывает высокий уровень неравенства с рыночной властью, извлечением ренты и институциональными различиями (Stiglitz, 2012). Подобные исследования важны для настоящей работы, поскольку показывают, что распределение доходов формируется под воздействием совокупности экономических и институциональных условий, а не определяется одним макроэкономическим показателем.

Эмпирические исследования взаимосвязи экономического роста и неравенства демонстрируют неоднозначность выводов. Так, в работе Дейнингера и Сквайра обоснована зависимость характера взаимосвязи роста и распределения от качества международных статистических данных (Deininger & Squire, 1998). Результаты исследования Барро показали, что характер этой связи определяется уровнем развития страны (Barro, 2000). В исследовании Форбс выявлена положительная связь между неравенством и последующим экономическим ростом в среднесрочной перспективе (Forbes, 2000). Банерджи и Дюфло, напротив, обратили внимание на нелинейность и неустойчивость указанной зависимости (Banerjee & Duflo, 2003). В то же время в работе Ли и Цзоу показано, что неравенство не всегда выступает препятствием для экономического роста (Li & Zou, 1998). В совокупности рассмотренные исследования свидетельствуют о неоднозначности взаимосвязи экономического роста и доходного неравенства, результаты оценки которой зависят от направления анализа, временного горизонта

и спецификации эконометрической модели. В настоящем исследовании уровень ВВП на душу населения и темп его роста рассматриваются как самостоятельные объясняющие переменные, что позволяет разграничить достигнутый уровень экономического развития и краткосрочную динамику выпуска.

Важное место в научной литературе занимает вопрос о взаимосвязи внешнеэкономической открытости и распределения доходов. Теорема Столпера и Самуэльсона заложила теоретическую основу для анализа изменений относительных доходов факторов производства под воздействием международной торговли (Stolper & Samuelson, 1941). Однако последующие исследования показали, что распределительные эффекты торговли неоднозначны и не сводятся к единой схеме перераспределения доходов между трудом и капиталом либо между работниками различной квалификации. Так, Доллар и Краай рассматривали взаимосвязь торговой интеграции, экономического роста и доходов беднейших групп населения (Dollar & Kraay, 2004). Голдберг и Павчик выявили неоднородность распределительных эффектов торговой либерализации в развивающихся странах (Goldberg & Pavcnik, 2007). Мески и Виварелли показали, что связь международной торговли с доходным неравенством зависит, в частности, от структуры внешнеторговых связей и характеристик торговых партнеров (Meschi & Vivarelli, 2009). Жомот и соавторы установили, что динамика доходного неравенства связана не только с торговой и финансовой глобализацией, но и с технологическими изменениями (Jaumotte et al., 2013). В более позднем исследовании подчеркивается роль институционального качества как условия, определяющего характер взаимосвязи между торговой открытостью и доходным неравенством (Nam et al., 2024). Таким образом, связь внешнеэкономической открытости с распределением доходов зависит от структуры производства и внешней торговли, положения работников на рынке труда, особенностей торговых партнеров и институциональных условий, определяющих распределение выгод и адаптационных издержек внешнеэкономической интеграции.

Рынок труда является одним из основных механизмов формирования доходного нера-

венства, поскольку трудовые доходы составляют значительную часть доходов домохозяйств. Аутор и соавторы показали, что импортная конкуренция может сопровождаться существенными изменениями занятости и заработной платы на отдельных локальных рынках труда (Autor et al., 2013). Аджемоглу и Рестрепо рассматривают, каким образом автоматизация и возникновение новых трудовых задач изменяют спрос на труд и его роль в производственном процессе (Acemoglu & Restrepo, 2019). В совокупности эти исследования свидетельствуют о том, что технологические изменения, внешнеторговые шоки и структурные сдвиги на рынке труда могут сопровождаться усилением различий между работниками в зависимости от образования, квалификации, отраслевой принадлежности и места проживания. В связи с этим уровень безработицы рассматривается в настоящем исследовании как самостоятельная характеристика состояния рынка труда, потенциально связанная с распределением доходов населения.

Природная рента также рассматривается в научной литературе как один из факторов, связанных с доходным неравенством. Парсеро и Папиракис исследуют взаимосвязь нефтяной ресурсной зависимости и распределения доходов в контексте гипотезы «ресурсного проклятия» (Parcero & Papirakis, 2016). Вместе с тем эмпирические исследования свидетельствуют о неоднородности данной зависимости. В частности, Савадого и Уоба выявляют различия в характере связи между природной рентой и доходным неравенством на основе модели конечных смесей регрессий (Sawadogo & Ouoba, 2024). Распределительные последствия использования природных ресурсов могут определяться механизмами перераспределения рентных доходов, структурой национальной экономики и особенностями институциональной среды. Направление ресурсных поступлений на развитие инфраструктуры и финансирование социальных расходов способно создавать предпосылки для сокращения неравенства, тогда как концентрация этих доходов в отдельных секторах экономики и группах населения может сопровождаться усилением доходной дифференциации.

Наряду с уровнем экономического разви-

тия, ростом ВВП, торговой открытостью, безработицей и природной рентой в исследованиях доходного неравенства рассматриваются показатели урбанизации и инфляции. Урбанизация связана с территориальной концентрацией экономической активности, размещением рабочих мест и различиями в доступе населения к образованию, инфраструктуре и социальным услугам. При этом ее взаимосвязь с распределением доходов неоднозначна: расширение городского сектора может создавать дополнительные экономические возможности, тогда как неравномерность территориального развития способна сопровождаться усилением доходной дифференциации. В исследованиях, посвященных Казахстану, также отмечается значимость региональных и районных различий в формировании неравенства благосостояния населения (Kireyeva et al., 2023; Kudebayeva & Sätre, 2024).

Инфляция рассматривается как дополнительная макроэкономическая характеристика, имеющая значение для распределения доходов вследствие неодинакового воздействия роста цен на покупательную способность различных групп населения. Характер данной взаимосвязи зависит от структуры доходов домохозяйств, механизмов индексации, уровня социальной защиты и общей макроэкономической среды (Atkinson, 2015; Stiglitz, 2012; Spankulova et al., 2026). Таким образом, урбанизация и инфляция включаются в настоящее исследование в качестве самостоятельных объясняющих переменных, статистическая связь которых с индексом Джини подлежит эмпирической проверке.

Исследования доходного неравенства в Казахстане охватывают макроэкономические, институциональные и региональные аспекты. Хоуи и Атаханова рассматривают распределительные последствия ресурсного бума с учетом отраслевой и территориальной структуры экономики (Howie & Atakhanova, 2014). Жанбозова и соавторы на основе данных за 2001–2023 гг. выявляют статистически значимые взаимосвязи индекса Джини с качеством институтов, инвестициями, структурой экономики, безработицей и социальными характеристиками (Zhanbozova et al., 2026).

Региональные особенности доходного

неравенства раскрываются в исследованиях Темербулатовой и соавторов, рассматривающих краткосрочные и долгосрочные взаимосвязи экономического роста и неравенства в регионах Казахстана (Temerbulatova et al., 2024), а также Кудебаевой и Сэтре, оценивающих вклад регионального и районного уровней в дифференциацию благосостояния домохозяйств на основе данных за 2018–2021 гг. (Kudebayeva & Sätre, 2024).

Отдельное направление исследований связано с неравенством трудовых доходов. Нурланова и соавторы рассматривают его региональные и отраслевые особенности (Nurlanova et al., 2024), тогда как Глеубердинова и соавторы анализируют региональные и секторальные различия заработной платы с учетом характеристик работников и предприятий (Tleuberdinova et al., 2024). В совокупности данные исследования подчеркивают значение структурных, территориальных и трудовых характеристик для анализа доходной дифференциации.

В исследованиях последних лет доходное неравенство в Казахстане рассматривается во взаимосвязи с образованием, структурой доходов и макроэкономическими условиями. Киреева и соавторы анализируют региональные различия в распределении доходов и образовании (Kireyeva et al., 2023), тогда как Зейнулла и соавторы рассматривают роль образования в сокращении доходной дифференциации (Zeinolla et al., 2025). Аширбекова и соавторы исследуют дифференциацию доходов населения и возможности их прогнозирования (Ashirbekova et al., 2023). Жанбырбаева и соавторы рассматривают особенности экономического неравенства в Казахстане (Zhanbyrbayeva et al., 2024), а Спанкулова и соавторы оценивают связь регионального доходного неравенства с характеристиками здравоохранения и макроэкономической нестабильностью (Spankulova et al., 2026).

Проведённый литературный обзор свидетельствует о неоднозначности взаимосвязей между доходным неравенством и основными экономическими характеристиками. Направление и устойчивость выявляемых зависимостей могут различаться в зависимости от структуры экономики, институциональных условий, сос-

тава выборки и используемой методологии. Несмотря на наличие комплексных страновых и региональных исследований, сохраняется необходимость сопоставления статистических связей индекса Джини с уровнем экономического развития, ростом ВВП, безработицей, торговой открытостью, природной рентой, урбанизацией и инфляцией в рамках единой межстрановой панельной модели. Такой подход позволяет оценить, какие из рассматриваемых характеристик сохраняют устойчивую связь с неравенством при анализе внутривременных изменений во времени.

МАТЕРИАЛЫ И МЕТОДЫ

Информационную базу исследования составили данные World Development Indicators (WDI) и Poverty and Inequality Platform (PIP) Всемирного банка. В качестве зависимой переменной использован индекс Джини, характеризующий степень неравномерности распределения доходов либо потребления домохозяйств. Выбор данного показателя обусловлен широким охватом стран, доступностью международных статистических данных и его распространенным применением в эмпирических исследованиях экономического неравенства.

Исследовательская выборка охватывает 93 страны за 2002–2021 гг. и включает 1 369 наблюдений формата «страна–год». Панель имеет несбалансированную структуру, обусловленную различиями в периодичности проведения национальных обследований домохозяйств и доступности соответствующих статистических показателей. При полностью сбалансированной панели число наблюдений составило бы 1 860, однако фактический объем выборки определяется наличием данных по зависимой и всем объясняющим переменным. Для проверки устойчивости полученных оценок дополнительно сформирована ограниченная выборка, включающая страны с не менее чем восемью наблюдениями по индексу Джини. В результате ее объем составил 74 страны и 1 284 наблюдения.

При формировании выборки учитывались различия в концепции измерения благосостояния, используемой Всемирным банком

при расчете индекса Джини. В базе Poverty and Inequality Platform данный показатель может основываться на распределении доходов либо потребления домохозяйств. На основе соответствующих метаданных наблюдения были разделены на две подвыборки: первая включает 997 наблюдений по 57 странам, в которых индекс Джини рассчитан по доходам, вторая – 372 наблюдения по 36 странам, использующим показатели потребления. Для каждой подвыборки отдельно оценена базовая модель со страновыми фиксированными эффектами.

Отбор объясняющих переменных основан на теоретических предположениях и результатах

предшествующих исследований, согласно которым распределение доходов может быть связано с уровнем экономического развития, текущей макроэкономической динамикой, состоянием рынка труда, степенью внешне-экономической открытости, ресурсной зависимостью, урбанизацией и инфляционной средой. Ожидаемые направления связи используются не как заранее заданные выводы, а как аналитические ориентиры для сопоставления эмпирических результатов с теоретическими положениями. Перечень переменных, их обозначения, содержание, единицы измерения и ожидаемые направления связи с индексом Джини представлены в таблице 1.

Таблица 1. Переменные исследования и предполагаемые направления связи с индексом Джини

Table 1. Research variables and hypothesized relationships with the Gini index

Переменная	Обозначение	Содержание и единица измерения	Ожидаемое направление связи
Индекс Джини	gini	Показатель неравенства доходов или потребления, пункты (0–100)	Зависимая переменная
ВВП на душу населения, ППС	Log_gdp_pc_ppp	Логарифм ВВП на душу населения по ППС	Отрицательное
Рост ВВП	gdp_growth	Годовой темп роста реального ВВП, %	Отрицательное
Безработица	unemployment	Доля безработных в рабочей силе, %	Положительное
Торговая открытость	trade_openness	Сумма экспорта и импорта товаров и услуг, % ВВП	Положительное
Природная рента	natural_resource_rents	Совокупная рента от природных ресурсов, % ВВП	Положительное
Урбанизация	urban_population	Доля городского населения в общей численности населения, %	Отрицательное
Инфляция	inflation	Годовой темп инфляции, %	Положительное

Примечание: составлено авторами на основе данных World Bank (2025)

Эконометрический анализ проводился поэтапно. На первом этапе рассчитаны описательные статистики, характеризующие структуру выборки, средние значения, вариацию и диапазоны исследуемых переменных. На втором этапе построена корреляционная матрица для предварительной оценки направления и силы парных взаимосвязей между показателями. Возможная мультиколлинеарность объясняющих переменных оценивалась с использованием коэффициентов инфляции дисперсии (VIF). Далее проведено панельное оценивание с сопоставлением объединенной модели наименьших квадратов (Pooled OLS), модели со случайными эффектами (RE) и модели с фиксированными эффектами (FE).

Выбор предпочтительной спецификации осуществлялся на основе F-теста, LM-теста Бройша–Пагана и теста Хаусмана.

По результатам модельной диагностики в качестве базовой выбрана модель со страновыми фиксированными эффектами. Данная спецификация позволяет оценивать статистические взаимосвязи между изменениями объясняющих переменных и индекса Джини внутри стран во времени, контролируя влияние ненаблюдаемых страновых характеристик, неизменных на протяжении рассматриваемого периода.

Для оценки связи экономических факторов с индексом Джини использована панельная модель с фиксированными страновыми эффек-

тами. Базовая спецификация имеет следующий вид:

$$\begin{aligned} Gini_{it} = & \beta_0 + \beta_1 LogGDPpc_{it} + \\ & + \beta_2 Growth_{it} + \beta_3 Unemployment_{it} + \\ & + \beta_4 TradeOpen_{it} \\ & + \beta_5 ResourceRents_{it} + \beta_6 UrbanPop_{it} + \\ & + \beta_7 Inflation_{it} + \mu_i + \varepsilon_{it} \end{aligned} \quad (1)$$

где:

$Gini_{it}$ — индекс Джини в стране i в году t ;
 $LogGDPpc_{it}$ — логарифм ВВП на душу населения по ППС;

$Growth_{it}$ — годовой темп роста ВВП;

$Unemployment_{it}$ — уровень безработицы;

$TradeOpen_{it}$ — торговая открытость;

$ResourceRents_{it}$ — совокупная природная рента в процентах ВВП;

$UrbanPop_{it}$ — доля городского населения, %;

$Inflation_{it}$ — годовой темп инфляции;

β_0 — константа;

$\beta_1 - \beta_7$ — коэффициенты при соответствующих объясняющих переменных;

μ_i — страновые фиксированные эффекты, учитывающие постоянные во времени ненаблюдаемые особенности страны;

ε_{it} — случайная ошибка.

Дополнительно проведены диагностические тесты на гетероскедастичность, серийную корреляцию и межстрановую зависимость ошибок. Полученные результаты свидетельствуют о наличии указанных нарушений, в связи с чем для статистического вывода использованы стандартные ошибки Дрисколла-Краая, устойчивые к гетероскедастичности, серийной корреляции и межстрановой зависимости (Driscoll & Kraay, 1998). Применение данного подхода учитывает особенности межстрановых панельных данных, в которых национальные

экономики могут подвергаться воздействию общих внешних шоков.

Устойчивость полученных результатов проверялась посредством четырех дополнительных спецификаций. Во-первых, оценена двусторонняя модель с фиксированными страновыми и годовыми эффектами (Two-way FE), позволяющая контролировать общие временные изменения. Во-вторых, использована нелинейная спецификация с включением квадрата логарифма ВВП на душу населения для проверки гипотезы Кузнецца. В-третьих, базовая модель повторно оценена на ограниченной выборке, включающей страны с не менее чем восемью наблюдениями по индексу Джини, что позволяет проверить чувствительность результатов к полноте временных рядов. В-четвертых, с учетом различий в концепции измерения благосостояния проведено раздельное оценивание модели для подвыборок, в которых индекс Джини рассчитан по доходам и потреблению домохозяйств.

Полученные коэффициенты интерпретируются как оценки статистических взаимосвязей между экономическими характеристиками и индексом Джини при анализе внутривременных изменений во времени, а не как причинные эффекты. Возможность причинной интерпретации ограничена потенциальной обратной причинностью, одновременностью изменений и влиянием ненаблюдаемых факторов, изменяющихся во времени.

РЕЗУЛЬТАТЫ

Сформированная межстрановая панель характеризуется существенными различиями как по уровню доходного неравенства, так и по основным экономическим показателям. Для оценки диапазона их изменения и общей неоднородности выборки рассчитаны описательные статистики по 93 странам за 2002–2021 гг., включающие 1 369 наблюдений (таблица 2).

Таблица 2. Структура выборки и описательная статистика переменных
Table 2. Sample composition and descriptive statistics of the variables

Переменная / показатель	N	Среднее	Ст. откл.	Мин.	Макс.
Количество стран	93	-	-	-	-
Количество наблюдений	1 369	-	-	-	-
Период наблюдения	2002–2021	-	-	-	-
Индекс Джини	1 369	36.18	7.99	23.20	65.00

ln ВВП на душу населения	1 369	10.06	0.87	7.04	11.84
Рост ВВП, %	1 369	3.26	4.12	-16.04	24.62
Безработица, %	1 369	7.96	5.33	0.25	37.32
Торговая открытость, % ВВП	1 369	90.70	49.25	22.11	397.51
Природная рента, % ВВП	1 369	2.98	5.22	0.00	42.22
Урбанизация, % населения	1 369	67.46	16.53	12.20	95.51
Инфляция, %	1 369	4.33	5.87	-4.45	59.22

Примечание: составлено авторами

Среднее значение индекса Джини в исследуемой выборке составляет 36.18 пункта при стандартном отклонении 7.99. Значения показателя варьируются от 23.20 до 65.00, что свидетельствует о существенной неоднородности наблюдений по уровню неравенства. Значительный разброс характерен и для макроэкономических показателей: торговая

открытость изменяется от 22.11 до 397.51 % ВВП, совокупная природная рента — от 0.00 до 42.22 % ВВП, а уровень безработицы — от 0.25 до 37.32 %.

Для наглядной характеристики зависимой переменной на рисунке 1 представлено распределение индекса Джини в межстрановой панели.

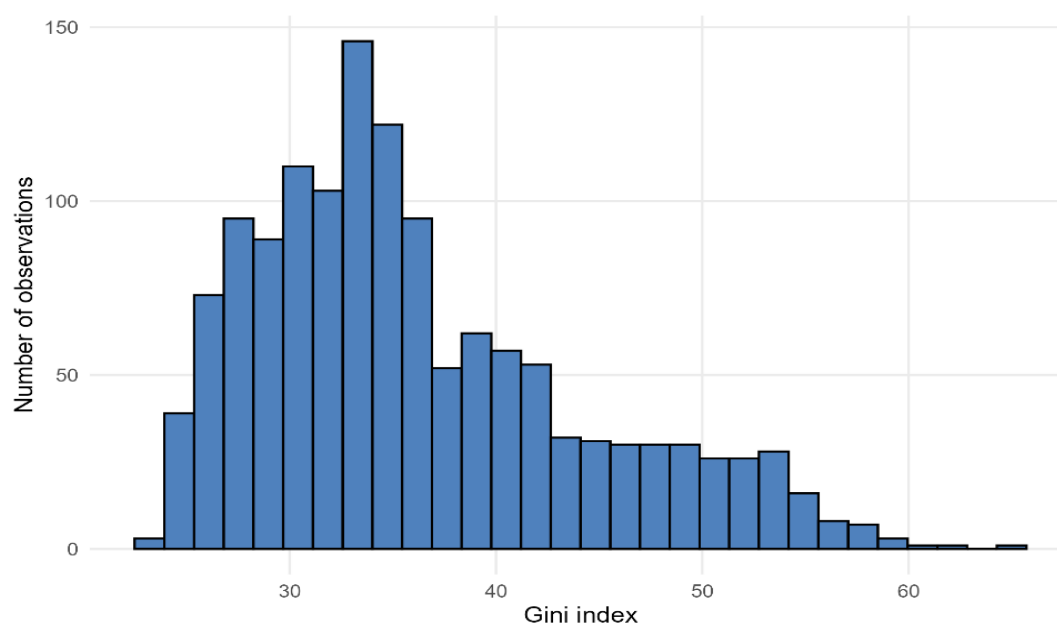


Рисунок 1. Распределение индекса Джини в межстрановой панели

Figure 1. Distribution of the Gini index in the cross-country panel

Основная часть наблюдений сосредоточена в среднем диапазоне значений, тогда как высокие показатели неравенства встречаются значительно реже. При этом наличие наблюдений с индексом Джини свыше 50 пунктов указывает на заметные различия в уровне неравенства в исследуемой выборке. Вместе с тем распределение не ограничивается узким интервалом: в выборке присутствуют наблюдения, в которых индекс Джини превышает

50 пунктов, что свидетельствует о существенной дифференциации рассматриваемых экономик по характеру распределения доходов и потребления. Выявленная вариация индекса Джини определяет необходимость дальнейшего анализа его взаимосвязей с макроэкономическими и структурными характеристиками.

После оценки распределения индекса Джини проведен корреляционный анализ для предварительного выявления взаимосвязей

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между исследуемыми переменными. Представленная на рисунке 2 корреляционная

матрица позволяет сопоставить направление и тесноту парных связей между показателями.

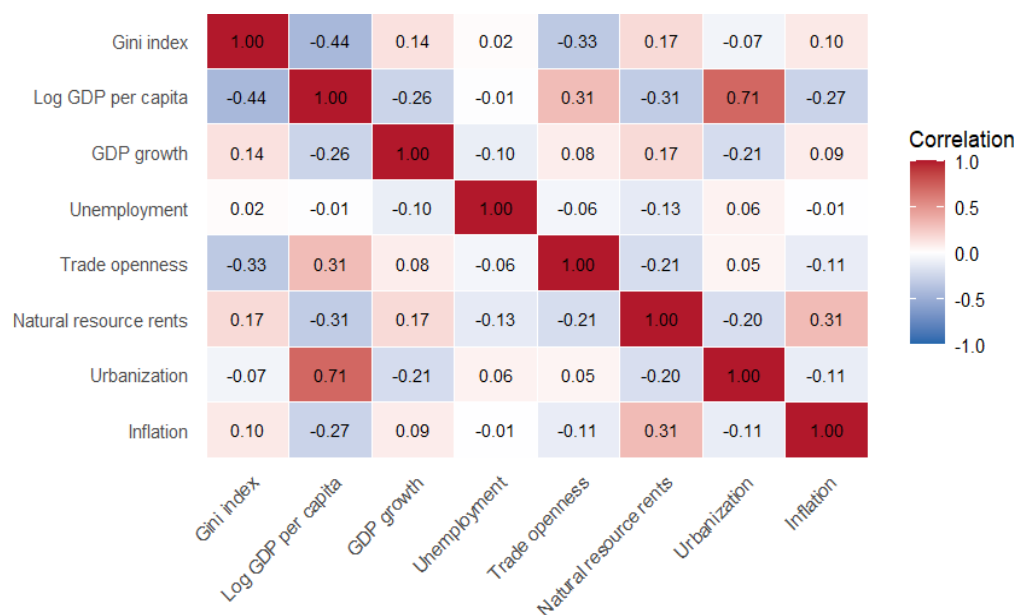


Рисунок 2. Корреляционная матрица переменных исследования

Figure 2. Correlation matrix for the study variables

Корреляционная матрица показывает, что наиболее выраженная отрицательная связь индекса Джини наблюдается с логарифмом ВВП на душу населения ($r = -0.44$) и торговой открытостью ($r = -0.33$). Положительные, но относительно слабые корреляции выявлены с природной рентой ($r = 0.17$), ростом ВВП ($r = 0.14$) и инфляцией ($r = 0.10$). Связь индекса Джини с безработицей ($r = 0.02$) и урбанизацией ($r = -0.07$) практически отсутствует. Среди объясняющих переменных выделяется высокая положительная корреляция между логарифмом

ВВП на душу населения и уровнем урбанизации ($r = 0.71$). Остальные парные коэффициенты по абсолютной величине не превышают 0.31. Полученные результаты характеризуют предварительные взаимосвязи между показателями без учета страновых особенностей и совместного влияния регрессоров. Наличие относительно высокой корреляции между ВВП на душу населения и урбанизацией обуславливает необходимость дополнительной проверки мультиколлинеарности (таблица 3).

Таблица 3. Проверка мультиколлинеарности

Table 3. Multicollinearity diagnostics

Переменная	VIF
Log ВВП на душу населения, ППС	2.692
Рост ВВП	1.136
Безработица	1.041
Торговая открытость	1.248
Природная рента	1.243
Урбанизация	2.189
Инфляция	1.168

Примечание: составлено авторами

Проверка мультиколлинеарности выполнена с использованием коэффициентов инфляции

дисперсии (VIF), значения которых находятся ниже порогового уровня 5, что позволяет

сделать вывод об отсутствии критической мультиколлинеарности между независимыми переменными. Наибольшее значение VIF наблюдается для логарифма ВВП на душу населения (2,692), второе по величине – для урбанизации (2,189). Следовательно, несмотря на заметную корреляцию между этими пока-

зателями, их одновременное включение в модель не создает критического риска мультиколлинеарности.

Для выбора адекватной панельной спецификации и проверки эконометрических предпосылок были проведены диагностические тесты (таблица 4).

Таблица 4. Диагностические тесты и выбор модели

Table 4. Diagnostic tests and model selection

Диагностическая процедура	Статистика / значение	p-value	Вывод
Hausman test: fixed effects vs random effects	55.917	9.81e-10	Предпочтительна FE-модель
F-test: fixed effects vs pooled OLS	118.287	<0.001	FE лучше pooled OLS
Breusch-Pagan LM test: random effects vs pooled OLS	7469.459	<0.001	Pooled OLS отвергается
Panel serial correlation test	438.982	1.80e-97	Выявлена автокорреляция
Cross-sectional dependence test	3.379	0.000728	Выявлена межстрановая зависимость
Breusch-Pagan heteroskedasticity test	200.630	8.44e-40	Выявлена гетероскедастичность

Примечание: составлено авторами

Результаты диагностических тестов подтверждают целесообразность использования модели со страновыми фиксированными эффектами. F-тест выявил статистическую значимость индивидуальных эффектов, а LM-тест Бройша–Пагана показал преимущество учета панельной структуры данных по сравнению с объединенной регрессией. Тест Хаусмана позволил сделать окончательный выбор в пользу FE-модели ($p < 0.001$). Вместе

с тем дополнительная диагностика выявила серийную корреляцию, межстрановую зависимость ошибок и гетероскедастичность. Наличие указанных нарушений обусловило применение стандартных ошибок Дрисколла–Краая при оценке статистической значимости регрессионных коэффициентов. Результаты оценивания базовой модели и дополнительных проверок устойчивости представлены в таблице 5.

Таблица 5. Основные регрессионные результаты и проверки устойчивости

Table 5. Main regression results and robustness checks

Переменная	FE DK	Two-way FE DK	Kuznets FE DK	Ограниченная FE DK
Log ВВП на душу населения, ППС	-4.795*** (0.679)	-2.193*** (0.506)	-15.309** (7.402)	-4.899*** (0.624)
Квадрат ln ВВП на душу населения	-	-	0.547 (0.354)	-
Рост ВВП	0.024 (0.017)	0.002 (0.025)	0.024 (0.019)	0.024 (0.017)
Безработица	0.068** (0.033)	0.093*** (0.029)	0.082*** (0.031)	0.070** (0.035)
Торговая открытость	0.027*** (0.004)	0.036*** (0.006)	0.024*** (0.005)	0.027*** (0.005)
Природная рента	0,063 (0.040)	0.057 (0.036)	0.070* (0.041)	0.045 (0.047)
Урбанизация	-0.055** (0.028)	0.005 (0.026)	-0.049* (0.029)	-0.050* (0.030)
Инфляция	-0.025 (0.019)	-0.031 (0.020)	-0.023 (0.018)	-0.016 (0.017)
Страновые эффекты	Да	Да	Да	Да
Годовые эффекты	Нет	Да	Нет	Нет

Стандартные ошибки	Driscoll-Kraay	Driscoll-Kraay	Driscoll-Kraay	Driscoll-Kraay
Наблюдения	1 369	1 369	1 369	1 284
Страны	93	93	93	74

*В скобках приведены стандартные ошибки Дрисколла–Краая, рассчитанные с максимальным лагом 3. Уровни статистической значимости: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$. Модель FE DK включает страновые фиксированные эффекты; Two-way FE DK – страновые и годовые фиксированные эффекты; Kuznets FE DK — квадратичный член логарифма ВВП на душу населения. Ограниченная FE DK оценена на выборке стран, имеющих не менее восьми наблюдений по индексу Джини.*

Примечание: составлено авторами

При интерпретации регрессионных результатов необходимо учитывать масштаб объясняющих переменных и особенности модели с фиксированными эффектами. Поскольку ВВП на душу населения включен в логарифмической форме, его коэффициент характеризует связь относительного изменения данного показателя с изменением индекса Джини внутри стран во времени. В базовой FE-модели коэффициент составляет -4.795 , что соответствует снижению индекса Джини приблизительно на 0.048 пункта при увеличении ВВП на душу населения на 1% , при прочих равных условиях. Для остальных объясняющих переменных, выраженных в процентах или процентах ВВП, коэффициенты отражают изменение индекса Джини при увеличении соответствующего показателя на один процентный пункт.

Наиболее устойчивые результаты получены для ВВП на душу населения. Коэффициент при его логарифме сохраняет отрицательный знак и статистическую значимость во всех рассматриваемых спецификациях, включая базовую FE-модель ($\beta = -4.795$; $p < 0.01$), модель со страновыми и годовыми фиксированными эффектами, нелинейную спецификацию и модель, оцененную на ограниченной выборке. В базовой модели увеличение ВВП на душу населения приблизительно на 1% ассоциируется со снижением индекса Джини на 0.048 пункта при прочих равных условиях. Полученные оценки указывают на устойчивую отрицательную статистическую связь между изменением уровня экономического развития и доходным неравенством внутри стран. Вместе с тем они не предполагают причинной интерпретации, поскольку использование фиксированных эффектов не исключает возможной эндогенности, обусловленной обратной причинностью и ненаблюдаемыми факторами,

изменяющимися во времени.

Проверка нелинейной зависимости не выявила эмпирического подтверждения гипотезы Кузнецца. Коэффициент при квадрате логарифма ВВП на душу населения имеет положительный знак ($\beta = 0.547$), однако статистически незначим. Следовательно, полученные результаты не позволяют подтвердить наличие перевернутой U-образной зависимости между уровнем экономического развития и индексом Джини в рассматриваемой выборке.

В отличие от ВВП на душу населения, годовой темп экономического роста не демонстрирует статистически значимой связи с индексом Джини ни в одной из основных спецификаций. В базовой модели коэффициент составляет 0.024 , а после включения годовых фиксированных эффектов снижается до 0.002 , оставаясь статистически незначимым. Полученные результаты свидетельствуют о необходимости разграничения достигнутого уровня экономического развития и краткосрочной динамики выпуска при исследовании доходного неравенства. Отсутствие значимой связи между темпами роста ВВП и индексом Джини указывает на то, что увеличение совокупного выпуска само по себе не обязательно сопровождается сокращением доходной дифференциации. Данный результат следует рассматривать в контексте исследований, отмечающих неоднозначность взаимосвязей между экономическим ростом и неравенством (Banerjee & Duflo, 2003; Barro, 2000; Deininger & Squire, 1998; Forbes, 2000; Li & Zou, 1998).

Результаты по безработице подтверждают значение рынка труда как одного из центральных каналов формирования доходной дифференциации. Коэффициент при данном показателе положителен и статистически значим в основных спецификациях со стандартными

ошибками Дрисколла-Краая. В базовой модели увеличение уровня безработицы на один процентный пункт связано с ростом индекса Джини приблизительно на 0,068 пункта при прочих равных условиях. Экономическая интерпретация этого результата состоит в том, что ограничение доступа к трудовым доходам усиливает различия между занятыми и незанятыми домохозяйствами, а также повышает риск концентрации доходов у групп, сохраняющих устойчивое положение на рынке труда. Сохранение положительной связи в двухсторонней FE-модели и в ограниченной выборке показывает, что данный результат не сводится ни к общей временной динамике, ни к особенностям несбалансированной панели. Он также согласуется с исследованиями, в которых изменения на рынке труда, импортная конкуренция и технологические сдвиги рассматриваются как факторы, способные усиливать различия в занятости и заработках (Acemoglu & Restrepo, 2019; Autor et al., 2013).

Торговая открытость демонстрирует наиболее последовательную положительную связь с индексом Джини: ее коэффициент статистически значим во всех ключевых спецификациях. В базовой модели увеличение торговой открытости на один процентный пункт ВВП ассоциируется с ростом индекса Джини примерно на 0,027 пункта, тогда как увеличение на 10 процентных пунктов соответствует росту приблизительно на 0,27 пункта. Этот результат требует особенно осторожной интерпретации, поскольку он отличается от отрицательной парной корреляции между торговой открытостью и индексом Джини. Расхождение объясняется различием аналитических уровней: корреляционный анализ отражает преимущественно межстрановые различия, тогда как FE-модель использует внутристрановую динамику. Поэтому более открытые экономики в среднем могут характеризоваться более низким уровнем неравенства, однако увеличение открытости внутри одной и той же страны во времени способно сопровождаться усилением доходной дифференциации. В этом смысле полученный результат соответствует исследованиям о неоднозначных распределительных последствиях глобализации и внешней торговли (Goldberg & Pavcnik, 2007;

Jaumotte et al., 2013; Meschi & Vivarelli, 2009; Nam et al., 2024), но уточняет их за счет панельной оценки: торговая открытость не является универсальным фактором снижения или роста неравенства, поскольку ее последствия зависят от распределения внешнеторговых выгод и адаптационных издержек между секторами, регионами и группами работников.

Результаты по урбанизации, природной ренте и инфляции имеют менее устойчивый характер. Урбанизация отрицательно связана с индексом Джини в базовой FE-модели, что может отражать роль городского развития в расширении доступа к занятости, инфраструктуре и социальным услугам; однако после включения годовых эффектов статистическая значимость данного показателя исчезает. Поэтому урбанизацию целесообразно рассматривать как фактор, чувствительный к спецификации, а не как устойчивый коррелят доходного неравенства. Природная рента преимущественно имеет положительный знак, но ее статистическая значимость нестабильна, что не позволяет сделать вывод о наличии устойчивой связи между ресурсной зависимостью и индексом Джини в рассматриваемой панели. Более корректная интерпретация состоит в том, что распределительные последствия рентных доходов, вероятно, зависят от институциональной среды, фискальных механизмов, структуры собственности и качества государственного управления (Parcerro & Papayakis, 2016; Sawadogo & Ouoba, 2024). Инфляция также не показывает стабильной статистической связи с индексом Джини.

Проверка устойчивости по составу несбалансированной панели подтверждает основные выводы. После исключения стран, имеющих менее восьми наблюдений по индексу Джини, ограниченная выборка составила 1 284 наблюдения по 74 странам. При этом знаки и статистическая значимость коэффициентов при ВВП на душу населения, безработице и торговой открытости сохраняются. Следовательно, выявленные связи не являются следствием включения стран с единичными или редкими наблюдениями и сохраняются при более строгом требовании к полноте данных.

Дополнительная проверка устойчивости была проведена с учетом различий в концепции

благосостояния, используемой при расчете индекса Джини. Для этого базовая модель с фиксированными страновыми эффектами была отдельно оценена для наблюдений, в

которых индекс Джини рассчитан по доходам, и для наблюдений, основанных на потреблении. Результаты представлены в таблице 6.

Таблица 6. Проверка устойчивости результатов с учетом концепции благосостояния, используемой при расчете индекса Джини

Table 6. Robustness check by welfare concept underlying the Gini index

Переменная	Gini по доходам	Gini по потреблению
Log ВВП на душу населения, ППС	-4.850*** (0.548)	-4.384*** (0.743)
Рост ВВП	-0.013 (0.015)	0.119*** (0.024)
Безработица	0.073** (0.032)	0.125** (0.054)
Торговая открытость	0.030*** (0.006)	0.041*** (0.011)
Природная рента	0.095 (0.100)	0.029 (0.035)
Урбанизация	-0.344*** (0.054)	0.116*** (0.019)
Инфляция	-0.051* (0.027)	-0.037* (0.020)
Страновые эффекты	Да	Да
Стандартные ошибки	Driscoll-Kraay	Driscoll-Kraay
Наблюдения	997	372
Страны	57	36

*В скобках приведены стандартные ошибки Дрисколл-Краая с максимальным лагом 3; *** $p < 0,01$, ** $p < 0,05$, * $p < 0,10$. Разделение выборки выполнено в соответствии с концепцией благосостояния, используемой Всемирным банком при расчете индекса Джини: доходы или потребление.*

Раздельное оценивание по типу показателя благосостояния подтвердило устойчивость основных взаимосвязей, выявленных в базовой модели (таблица 6). Коэффициент при логарифме ВВП на душу населения сохраняет отрицательный знак и статистическую значимость как в подвыборке, основанной на доходах ($\beta = -4.850$; $p < 0.01$), так и в подвыборке, основанной на потреблении ($\beta = -4.384$; $p < 0.01$). Положительная статистически значимая связь с индексом Джини также сохраняется для безработицы и торговой открытости.

Наиболее заметные различия между подвыборками выявлены для экономического роста и урбанизации. Коэффициент при темпе роста ВВП статистически незначим при использовании индекса Джини по доходам ($\beta = -0.013$), тогда как в подвыборке, основанной на потреблении, наблюдается положительная статистически значимая связь ($\beta = 0.119$; $p < 0.01$). Для урбанизации различается не только величина, но и направление коэффициента: -0.344 ($p < 0.01$) в первой подвыборке против 0.116 ($p < 0.01$) во второй. Природная рента не демонстрирует статистически значимой связи с индексом Джини ни в одной из моделей, тогда как коэффициент при инфляции в обоих случаях

имеет отрицательный знак и достигает лишь 10%-го уровня значимости.

Таким образом, результаты по ВВП на душу населения, безработице и торговой открытости сохраняются при раздельном оценивании двух подвыборок, тогда как оценки экономического роста и урбанизации характеризуются существенными различиями. При интерпретации последних следует учитывать, что подвыборки различаются не только концепцией измерения благосостояния, но и составом стран, что не позволяет однозначно отнести выявленные расхождения исключительно к способу расчета индекса Джини.

Сопоставление результатов основных моделей и дополнительных проверок устойчивости с выдвинутыми гипотезами показывает, что наиболее последовательные статистические взаимосвязи выявлены для ВВП на душу населения, безработицы и торговой открытости. Отрицательный коэффициент при логарифме ВВП на душу населения сохраняет статистическую значимость во всех спецификациях, включая раздельное оценивание показателей Джини по доходам и потреблению, что согласуется с гипотезой H1. Положительная связь безработицы с индексом Джини также

сохраняется при изменении спецификации и состава выборки, подтверждая устойчивость результата, предусмотренного гипотезой Н3. Аналогичные результаты получены для торговой открытости: положительный знак и статистическая значимость коэффициента воспроизводятся во всех рассмотренных моделях, что соответствует гипотезе Н4.

Остальные гипотезы не получили устойчивого эмпирического подтверждения. Для темпа роста ВВП ожидаемая отрицательная связь не выявлена (Н2), тогда как положительный коэффициент при природной ренте не сохраняет статистическую значимость в большинстве спецификаций (Н5). Отрицательная связь урбанизации с индексом Джини наблюдается лишь в отдельных моделях и меняет направление в подвыборке, основанной на потреблении, вследствие чего гипотеза Н6 также не подтверждается. Результаты по инфляции не соответствуют предполагаемому положительному направлению связи (Н7): в основных спецификациях коэффициент статистически незначим, а при раздельном оценивании двух подвыборок имеет отрицательный знак. Таким образом, наиболее устойчивые результаты исследования относятся к уровню экономического развития, состоянию рынка труда и торговой открытости, тогда как оценки остальных факторов характеризуются большей чувствительностью к спецификации модели и составу выборки.

ЗАКЛЮЧЕНИЕ

Проведенное исследование позволило выявить три экономические характеристики, сохраняющие устойчивую статистическую связь с индексом Джини: ВВП на душу населения, безработицу и торговую открытость. Отрицательная связь ВВП на душу населения с индексом Джини, а также положительные коэффициенты при безработице и торговой открытости сохраняются в альтернативных спецификациях модели, при ограничении выборки по полноте наблюдений и раздельном оценивании показателей Джини, рассчитанных по доходам и потреблению. В отличие от указанных переменных, краткосрочный рост ВВП, природная рента, урбанизация и инфляция не демонстрируют сопоставимой устойчивости:

величина, направление и статистическая значимость отдельных коэффициентов изменяются в зависимости от спецификации модели и состава используемой выборки. Полученные результаты свидетельствуют о необходимости разграничения достигнутого уровня экономического развития и текущей динамики выпуска, а также учета состояния рынка труда и внешнеэкономической открытости при анализе доходного неравенства.

Полученные оценки характеризуют устойчивые внутристрановые статистические ассоциации, выявленные на основе межстрановой панельной выборки. Их причинная интерпретация ограничена возможностью обратной причинности, одновременностью изменений и влиянием ненаблюдаемых факторов, изменяющихся во времени. Модели с фиксированными эффектами позволяют учитывать постоянные страновые характеристики, однако не устраняют указанные источники эндогенности. Поэтому результаты исследования позволяют определить макроэкономические и структурные параметры, наиболее последовательно связанные с динамикой доходного неравенства внутри стран, сохраняя ограничения в отношении установления направления причинного воздействия.

Отрицательная связь ВВП на душу населения с индексом Джини сохраняется во всех проведенных проверках, что указывает на устойчивость взаимосвязи между достигнутым уровнем экономического развития и меньшей выраженностью доходной дифференциации в рассматриваемой панели. Для темпа роста ВВП сопоставимого результата не получено. В основных спецификациях и в выборке, основанной на доходах, его коэффициент статистически незначим, тогда как при использовании индекса Джини, рассчитанного по потреблению, выявляется положительная статистически значимая связь. Полученные различия подтверждают чувствительность краткосрочной динамики выпуска к способу измерения благосостояния и не позволяют рассматривать экономический рост как устойчивый коррелят снижения доходного неравенства.

Положительная связь безработицы с индексом Джини подтверждает значимость рынка труда как

одного из ключевых механизмов формирования доходной дифференциации. Ограниченный доступ к занятости и трудовым доходам усиливает различия между группами населения и повышает вероятность концентрации доходов у более защищенных участников экономической системы. Поэтому анализ доходного неравенства не может ограничиваться агрегированными макроэкономическими показателями; он должен учитывать качество рабочих мест, устойчивость занятости, профессиональную мобильность и способность экономики включать различные социальные и демографические группы в продуктивную трудовую деятельность.

Положительная связь торговой открытости с индексом Джини не должна рассматриваться как аргумент в пользу ограничения внешне-экономической интеграции. Более обоснованная интерпретация состоит в том, что расширение внешнеторговых связей может сопровождаться неодинаковым распределением выгод и адаптационных издержек между секторами, регионами и группами работников. В этих условиях внешнеторговая политика требует сопряжения с мерами в сфере занятости, профессиональной адаптации, развития человеческого капитала и регионального выравнивания.

Для Казахстана полученные результаты не являются прямым эмпирическим заключением, поскольку используемая модель основана на межстрановой панели и не выделяет страну в качестве самостоятельного объекта оценки. Вместе с тем они задают методологическую основу для последующего анализа национальных и региональных данных. Особое значение имеет проверка того, каким образом экономическое развитие, занятость и внешнеэкономическая интеграция связаны с распределением доходов между отраслями, территориями и группами работников. Такой подход позволит перейти от агрегированных оценок к выявлению конкретных механизмов распределения выгод и издержек экономического развития.

Ограничения исследования связаны с отсутствием полной причинной идентификации, особенностями сопоставимости международных данных по неравенству и возможной чувствительностью отдельных оценок к составу выборки. Раздельное оценивание наблюдений, в которых индекс Джини рассчитан по

доходам и потреблению, позволило учесть одно из основных различий в концепции измерения благосостояния и подтвердило устойчивость результатов по ВВП на душу населения, безработице и торговой открытости. Вместе с тем выявленные различия в оценках экономического роста и урбанизации показывают, что способ построения зависимой переменной сохраняет значение для интерпретации отдельных факторов. Перспективы дальнейшего исследования связаны с применением динамических панельных моделей и инструментальных переменных, использованием альтернативных баз данных по распределению доходов, а также проведением раздельных оценок для групп стран с различными структурными характеристиками. Дополнительные возможности предоставляет использование микроданных и региональной статистики, позволяющих детализировать механизмы связи экономического развития, занятости и внешнеэкономической интеграции с распределением доходов.

AUTHOR CONTRIBUTIONS

Conceptualization and theory: AZ, FA, AP and OC; research design: AZ; data collection: AP and OC; analysis and interpretation: AZ and FA; writing draft preparation: AZ; supervision: AP; correction of article: AZ, FA, AP and OC; proofread and final approval of article: AZ, FA, AP and OC. All authors have read and agreed to the published version of the manuscript.

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