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Impact of Investments on Productivity and Tourism Development in Bosnia and Herzegovina*

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Abstract

This paper examines the short- and long-run effects of investment on tourism value added and labour productivity in Bosnia and Herzegovina over the period 2000–2023. The analysis distinguishes between total investment in tourism and gross investment in long-term assets. Results indicate that long-term investments in fixed assets have a significant positive impact on both tourism value added and labour productivity: a 1% increase in gross investment in long-term assets raises tourism value added by 1.36% and labour productivity by 0.83%. In contrast, total investment in tourism exhibits a more complex pattern: while it positively affects tourism value added, it negatively affects labour productivity, highlighting a paradox whereby overall sector growth does not automatically translate into higher productivity per employee. This effect likely reflects structural constraints, including seasonality, spatial concentration of demand, prevalence of low-skilled or seasonal employment, and inefficient capital allocation. Short-run effects are limited, although the error-correction mechanism confirms stable adjustment

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toward long-run equilibrium, with approximately 60% of deviations corrected annually. The findings underscore the importance of sustained fixed-asset investment and capital deepening for enhancing sectoral output and labour productivity, while indicating that the quantity of investment alone is insufficient without addressing structural and institutional constraints.

Keywords: *tourism investment, productivity, cointegration, Bosnia and Herzegovina, fixed assets*

JEL classification*: O47, C32, Z32*

1. Introduction

Tourism is widely recognized as a catalyst of economic diversification and regional cohesion, accounting for 9.1% of global GDP and roughly one in eleven jobs worldwide (United Nations World Tourism Organization [UNWTO], 2024). In Bosnia and Herzegovina (BiH) the sector's direct contribution rose from 2.1% of GDP in 2000 to 5.4% in 2019, outpacing manufacturing and agriculture in relative terms (World Travel & Tourism Council [WTTC], 2024). Yet BiH continues to trail its Western-Balkan peers on value added per employee and on the share of gross fixed capital formation channelled into tourism. Although national strategies repeatedly emphasize investment as a policy lever, empirical evidence on how different categories of capital formation translate into productivity gains is still sparse.

In line with growth theory, capital deepening refers to an increase in the amount of capital available per worker, usually through investment in infrastructure, equipment and technology, which is expected to enhance labour productivity (Romer, 1990; Sharpley, 2020; Solow, 1956). However, in tourism, the productivity effects of investment depend not only on the volume of investment, but also on its structure and purpose. Ivanovic et al. (2011) emphasize that FDI is important for technological development and export capacity, but also note that a large share of foreign investment in Croatia was directed toward infrastructure, while stronger multiplier effects could be expected from investment in more technologically advanced and productive activities. This distinction is important because investment in tourism may increase capacity and output without necessarily improving labour productivity if it is not accompanied by technological upgrading, better business processes, higher service quality and greater value added per worker. In this context, the available literature has not sufficiently isolated the short- and long-run effects of total investment and fixed-asset investment on tourism value added and labour productivity, which defines the empirical contribution of the present study.

Unlike other CEE and Adriatic economies, Bosnia and Herzegovina represents a particularly specific case due to fragmented tourism governance, the absence of a harmonised state-level investment framework, and persistently low capital intensity despite sustained growth in tourist arrivals and overnight stays. In contrast to Croatia, where tourism investment has been more strongly integrated with productivity-enhancing accommodation upgrading, or Montenegro, where tourism expansion has been more clearly linked to targeted destination development, BiH combines demand growth with weak capital deepening, spatial concentration, and institutional fragmentation. These structural features make Bosnia and Herzegovina a particularly suitable case for analysing whether different forms of investment generate distinct long-run effects on tourism value added and labour productivity.

Against this background, the causal relationship between investment flows and tourism-sector performance in BiH remains insufficiently measured. Accordingly, this study quantifies both the short- and long-run effects of total investment in tourism (TI) and gross investment in long-term assets (GI) on tourism value added (AVT) as an indicator of sectoral development, and on value added per employee (AVPE) as an indicator of labour productivity.

The aim of the research is to clarify whether investment-led growth in Bosnia and Herzegovina's tourism sector leads to measurable productivity improvements, as well as to distinguish the short- and long-term effects of total investment in tourism and gross investment in long-term assets on total value added in tourism and productivity measured as added value per employee.

Hypotheses:

> H1: *Total Investments in the tourism sector have a positive impact on its development, measured by the added value of this sector, as well as on worker productivity.*
>
> H2: *Gross investment in long-term assets have a positive impact on its development, measured by the added value of this sector, as well as on worker productivity.*

By integrating investment-led growth theory with the tourism-led growth hypothesis, the research advances the understanding of how different categories of capital formation affect productivity in a small post-transition economy—a topic that remains under-represented in the literature. Methodologically, the study contributes by simultaneously distinguishing between total tourism investment and gross investment in long-term assets within an Autoregressive Distributed Lag – Error Correction Model (ARDL–ECM) framework applied to a data-constrained transition economy characterised by structural breaks and limited time-series observations. Empirically, the main novelty of the paper lies in identifying a paradoxical negative long-run effect of total tourism investment on labour productivity, in contrast to the generally positive productivity effects reported in much of the CEE and Adriatic tourism-investment literature. This finding suggests that the volume of investment alone is insufficient to improve productivity unless accompanied by institutional coordination, efficient capital allocation, and investment in productivity-enhancing fixed assets. The findings are intended to assist policymakers in designing incentive programmes, prioritising fixed-asset formation, public–private partnerships, and alternative financing instruments.

2. Literature review

The relationship between capital formation and tourism performance is usually framed within two complementary strands of theory. These two strands can be analytically distinguished as: (i) the investment–productivity nexus, which focuses on the role of capital deepening in enhancing labour productivity, and (ii) the tourism–growth nexus, which emphasises the contribution of tourism activity to overall economic performance. The first strand, referred to as the investment–productivity nexus, is grounded in the investment-led-growth paradigm rooted in Solow's (1956) neoclassical model and its endogenous extensions (Romer, 1990), which emphasise the role of capital deepening in enhancing labour productivity and output. The second strand, known as the tourism–growth nexus, is reflected in the tourism-led-growth (TLG) hypothesis, which posits that tourism receipts stimulate economic growth through export earnings, employment, and knowledge diffusion (Balaguer & Cantavella-Jordá, 2002). Recent empirical research (post-2010) integrates the two, suggesting that targeted tourism investment amplifies the TLG channel by lifting total-factor productivity (Dwyer et al., 2010).

Building on these two strands, this study integrates the investment–productivity and tourism–growth perspectives by examining total investment and gross investment in long-term assets as distinct drivers of tourism value added and labour productivity (AVPE). In this framework, AVT captures aggregate tourism performance in line with the tourism–growth literature, while AVPE reflects productivity dynamics associated with capital deepening.

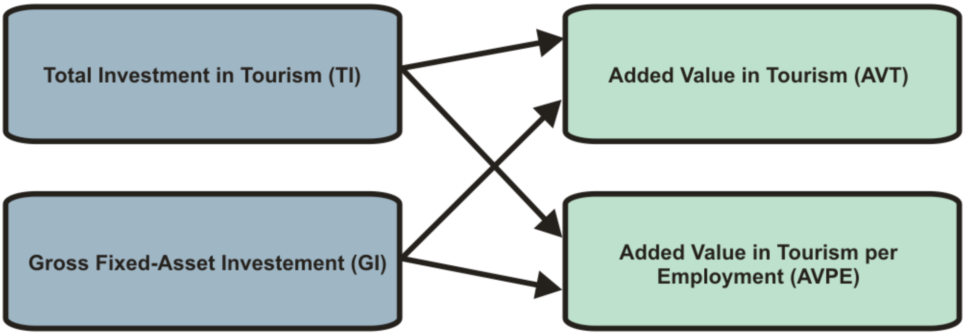
Empirical evidence suggests that tourism-related investment can support broader economic and social outcomes, although its productivity effects depend on the structure, purpose and institutional embeddedness of investment. Castilho and Fuinhas (2025), using a panel of 24 EU countries for the period 2006–2019, find that tourism capital investment contributes to reducing income inequality and poverty, indicating that tourism investment may have developmental effects beyond sectoral output alone. This argument is consistent with Sharpley's (2020) broader critique of sustainable tourism development, which stresses that tourism does not automatically generate sustainable development outcomes unless it is embedded in wider development processes and supported by appropriate policy and institutional conditions. Therefore, investment volume alone is insufficient to explain productivity effects in tourism; the structure, technological orientation and developmental quality of investment are equally important.

Regional evidence on tourism productivity remains limited and methodologically diverse. In Croatia, Perić and Nikšić Radić (2015) find that the stock of tourism FDI has a positive and statistically significant effect on tourism productivity, with education also making a positive contribution, while Bezić and Nikšić Radić (2017) show that tourism FDI is linked to tourism gross value added through cointegration and causality analysis. Ivanovic et al. (2011) further emphasize that FDI is important for technological development and export capacity, but warn that investment directed mainly toward infrastructure may produce weaker multiplier effects than investment in technologically advanced and higher value-added activities. In the Croatia–Slovenia context, Gričar et al. (2021) show that labour productivity and real gross wages in tourism are cointegrated, indicating that productivity dynamics represent an important factor in tourism labour-market outcomes. While these studies confirm the relevance of investment, FDI, value added and labour productivity in tourism, they do not directly examine whether total investment and gross investment in long-term assets contribute to changes in tourism value added and labour productivity, which defines the focus of the present study.

The European Bank for Reconstruction and Development (EBRD, 2022)'s Country Strategy flags fragmented project pipelines, while the World Bank (2022) warns that consumption-led recoveries lose momentum without complementary capital spending. The United Nations Development Programme (UNDP, 2025) reports a 32% year-on-year increase in arrivals following EU-funded upgrades in mountain resorts, yet offers no causal estimates. Macro-datasets reinforce these qualitative findings. Eurostat (2023) shows that BiH's capital stock per bed is 44% below the regional median. CEIC Data Company (2023) record a rebound to 96% of pre-pandemic receipts once gross fixed capital formation in accommodation returned to 2019 levels, while World Travel & Tourism Council (WTTC, 2024) emphasizes that tourism investment generates substantial multiplier effects throughout the economy, with the overall economic impact of tourism estimated to be approximately twice as large as its direct contribution once indirect and induced effects are included.

The literature suggests three stylised facts: (i) investment quality outweighs quantity, (ii) governance conditions the magnitude of spill-overs, and (iii) Western-Balkan evidence is fragmentary. No previous study has estimated short- and long-run effects of both total and fixed-asset investment on multiple productivity measures in BiH. Diagram 1 therefore proposes a conceptual model in which TI and GI affect AVT and AVPE through capital-deepening and spill-over channels moderated by institutional quality. This model serves as the analytical basis for the ARDL–ECM estimations presented in Section 5.

Diagram 1: Conceptual diagram of investment channels to tourism productivity in Bosnia and Herzegovina



Source: Authors' construction

By empirically testing this framework, the present paper contributes to closing a triple gap: a country gap (BiH), a variable gap (TI vs. GI), and a methodological gap (long-run cointegration with productivity proxies in a data-constrained transition economy). In addition, the paper contributes empirically by showing that total tourism investment does not necessarily translate into higher labour productivity, thereby refining the conventional assumption that tourism investment has uniformly positive productivity effects.

3. Investment context and empirical analysis of tourism productivity in BiH (2000-2023)

Since the Dayton Peace Agreement, Bosnia and Herzegovina's economy has undergone three phases of post-war transition. The initial phase (1995–1999) was marked by aid-driven recovery and double-digit GDP growth, but tourism contributed less than 2% to GDP (World Bank, 2015). During the second phase (2000–2007), the economy expanded at a steady annual rate of around 5%, yet capital formation in tourism remained below 4% of total investment (Central Bank of Bosnia and Herzegovina [CBBH], n.d.). The third phase (2008–2020) saw economic stagnation, with average growth rates below 1%, but also the fastest expansion of the tourism sector: foreign tourist nights increased by 87%, and direct employment reached 12% of the labour force by 2019 (WTTC, 2024).

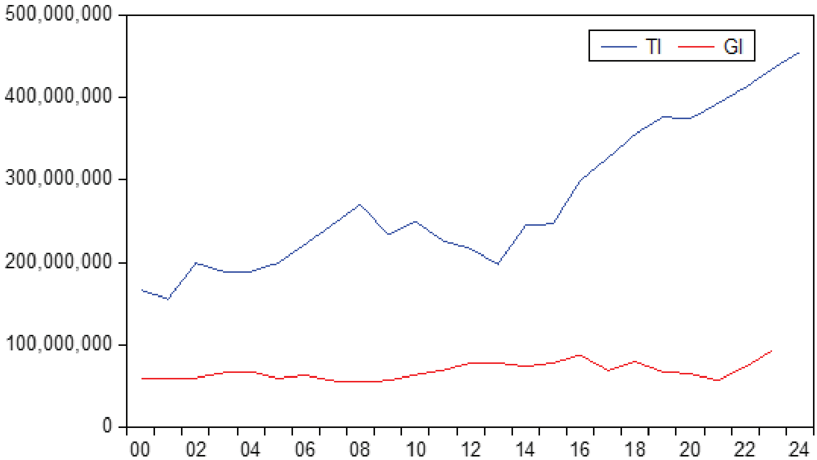
Despite strong demand-side growth—total tourist arrivals rose from 0.69 million in 2010 to 1.64 million in 2019, and overnight stays nearly doubled—Bosnia and Herzegovina captured only 5.4% of international tourism receipts in the region encompassing the former Yugoslavia and Albania, compared to Croatia's 53.1% and Slovenia's 14.3% (Centre for Excellence for Evaluation and Policy Research, 2022). The country offers a diverse but fragmented tourism product: Olympic ski resorts such as Jahorina and Bjelašnica, the coastal outlet of Neum, UNESCO sites in Mostar and Višegrad, and a growing cluster of eco- and wellness destinations. However, more than 70% of overnight stays remain concentrated in Sarajevo, Neum, and Mostar, while 40% of travel-export earnings are generated in the third quarter, illustrating persistent spatial and seasonal imbalances (CBBH, n.d.; International Finance Corporation [IFC], 2021).

While these trends are widely recognised by policy institutions, the practical implementation of strategic planning remains uneven. For instance, although the 2021–2027 Tourism Development Strategy of Republika Srpska explicitly prioritises investment in highland health and wellness tourism, there is limited evidence of project execution beyond a few infrastructure upgrades in Jahorina and Teslić. The absence of a harmonised investment roadmap at the state level further fragments the capital allocation process, limiting the country's ability to attract large-scale private investment and to access EU structural funds.

Recent policy analyses converge on the view that the core barriers to scalable tourism investment lie not in capital scarcity, but in institutional fragmentation, limited project pipelines, and regulatory bottlenecks (EBRD, 2022; World Bank, 2022). Evidence from Croatia suggests that tourism-related foreign direct investment may contribute to tourism development, although its effects depend on the structure and efficiency of investment allocation (Ivanovic et al. 2011; Perić & Nikšić Radić, 2015). In addition, recent research indicates that tourism capital investment can generate broader socio-economic effects, further supporting the relevance of long-term capital formation in tourism development (Castilho & Fuinhas, 2025). In this context, Bosnia and Herzegovina's challenge is one of allocation efficiency and institutional readiness. Streamlined permitting procedures and the deployment of bundled debt–equity instruments could unlock private-sector investment, particularly in health, adventure, and winter tourism, while also supporting geographic diversification and reducing outbound migration. Compared to Montenegro, where the share of tourism in gross fixed capital formation surpassed 10% in the post-2015 period, BiH has consistently remained below 4% despite similar terrain and comparable regional accessibility. Moreover, EU-27 countries allocate on average 6–9% of public infrastructure budgets to tourism-related capital, further underscoring BiH's structural lag in investment orientation.

Annual series in this section originate from WTTC (tourism employment and investment), the Central Bank of Bosnia and Herzegovina (CBBH, balance-of-payments travel receipts) and the Agency for Statistics of Bosnia and Herzegovina (BHAS, arrivals, overnight stays, value-added indicators) (CBBH, n.d.; BHAS, 2023). The empirical window is restricted to 2000 to 2023—the earliest year in which the four core variables are simultaneously available: total investment in tourism, gross investment in long-term tourism assets, tourism value added and value added per worker**.**

Figure 1: Tourism investment (TI) and gross investment in long-term tourism (GI) assets in Bosnia and Herzegovina, 2000 – 2023



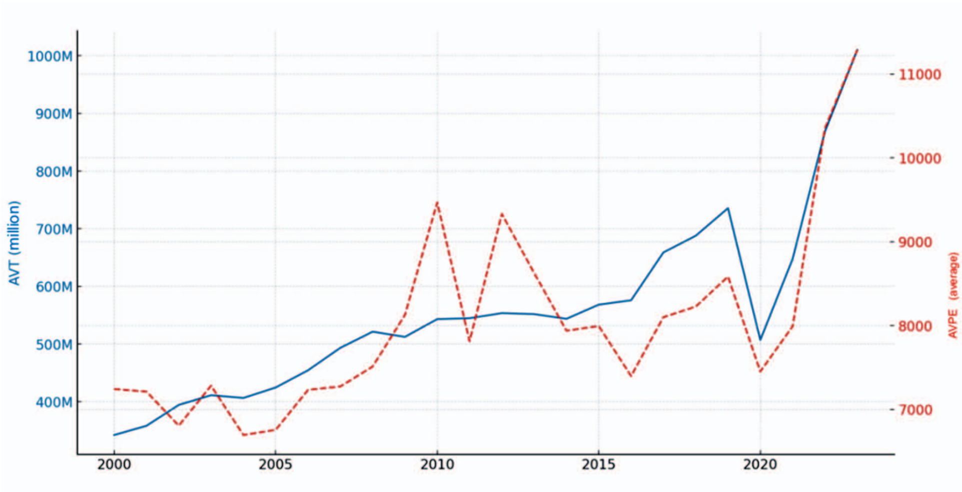
Source: Authors' calculations

Between 2000 and 2019 nominal TI rose from BAM 185 million to BAM 372 million, a compound annual growth rate of 3.7 percent (constant-2015 BAM unless stated otherwise). Yet GI remained shallow, seldom exceeding 4 percent of total national capital formation and, moreover, was heavily skewed toward accommodation facilities (see Figure 1).

Formal employment in tourism expanded from 57,000 in 2010 to 85,700 in 2019, before the Covid-19 contraction, and allowing for an estimated 30 percent shadow-economy share, total labour input is roughly one-third higher. The labour surge, however, did not translate into commensurate productivity growth: tourism's share of GDP slipped from 2.89 percent in 2000 to 2.08 percent in 2019, while AVPE has stagnated since 2011. Figure 2 depicts the divergent trajectories of AVT and AVPE.

International demand evolved in two waves: foreign arrivals grew 2.8-fold up to the 2008 crisis, paused briefly, and then tripled between 2010 and 2019, while overnight stays doubled in the latter surge (Centre for Excellence for Evaluation and Policy Research, 2022). Domestic arrivals increased more modestly—about 1.5-fold over 2010-2019—and were temporarily boosted by a pandemic voucher scheme in 2020. Despite rising volumes, average stays remain short (approximately two nights) and sharply seasonal: roughly 40 percent of travel-export revenue is earned in Q3, and more than 70 percent of registered overnights are concentrated in Sarajevo, Neum and Mostar (IFC, 2021). Such geographic and temporal concentration, coupled with limited GI, keeps annual bed utilisation below one-third and restrains productivity gains.

Figure 2: Tourism value added (AVT) and value added per worker (AVPE), 2000 – 2023



Source: Authors' calculations

Taken together, the descriptive evidence corroborates the study's premise: Bosnia and Herzegovina has achieved robust expansion in tourist volumes but only marginal improvements in value added and labour productivity, chiefly because capital deepening—captured by GI—has lagged behind demand. The cointegration and error-correction tests in Section 5 therefore examine whether stronger growth in TI, and above all in GI, can narrow this investment–productivity gap.

4. Methodology

This study examines the relationship between investment and the performance of the tourism sector in Bosnia and Herzegovina over the period 2000–2023, using annual data. This timeframe allows for the identification of long-term trends and the assessment of the effects of macroeconomic shocks and structural breaks in the sector.

Tourism development is measured by tourism value added, defined as the difference between the sector's total output and intermediate consumption, expressed in constant prices to remove the effects of inflation. AVT reflects the real value generated by tourism in the economy and is widely recognised in the literature as a key performance indicator, capturing tourism's direct, indirect, and induced contributions to gross domestic product (Stabler et al., 2010; UNWTO, 2014). In addition to AVT, the analysis employs labour productivity in tourism, measured as the ratio of value added to the number of employees. This approach provides insight into the efficiency of labour utilisation and represents a standard metric of productivity in both economic and tourism literature (Baum, 2015; Organisation for Economic Co-operation and Development [OECD], 2001).

The independent variables comprise tourism investment, including both total investment in the sector—encompassing gross fixed capital formation aimed at expanding capacity, modernising facilities, and improving service quality—and gross investment in long-term assets, covering expenditures on tangible and intangible assets such as accommodation facilities, land, equipment, software solutions, and licences. Long-term asset investment is of particular importance as it enables sustained productivity growth and sectoral resilience (Dwyer et al., 2010; Twining-Ward et al., 2017).

In this study, total investment in tourism refers to the broader aggregate measure of investment activity directed toward the tourism sector. It includes overall capital flows associated with the expansion, modernisation, and maintenance of tourism-related capacity, including investment in accommodation, supporting infrastructure, service facilities, and other tourism-related business activities. By contrast, gross investment in long-term assets refers more narrowly to investment in fixed and durable assets that remain in use over several accounting periods, such as buildings, accommodation facilities, land improvements, equipment, machinery, vehicles, software, licences, and other tangible or intangible long-term assets. Therefore, while TI captures the overall volume of investment activity in tourism, GI captures the fixed-asset component of capital formation that is more directly related to capital deepening and productivity-enhancing capacity.

Due to data limitations, investment is operationalised through total tourism investment and gross investment in long-term assets, which jointly capture overall capital formation in the tourism sector. While this operationalisation does not allow a direct distinction between public, private, and foreign direct investment, it reflects the aggregate structure of capital inflows available in official datasets. Moreover, previous empirical research suggests that investment in long-term assets serves as a robust proxy for productivity-enhancing capital, particularly in tourism sectors characterised by infrastructure constraints and capital scarcity. This distinction is particularly relevant in the context of Bosnia and Herzegovina, where the efficiency of capital allocation may be more important than the overall volume of investment.

All variables were transformed into natural logarithms to stabilise variance and allow coefficients to be interpreted as elasticities (Wooldridge, 2016). This operationalisation makes it possible to analyse both short- and long-term effects of investment on sectoral performance, revealing the mechanisms through which capital shapes productivity and tourism's contribution to overall economic growth.

Table 1 gives an overview of the used variables and data sources. Or A summary of the variables used within this research and their sources are presented in Table 1.

Table 1: Definition of Variables and Data Source

Symbol	Definition	Unit	Source	Expected sign
TI	Total investment in tourism	BAM million (2015)	WTTC, 2024	+
GI	Gross investment in long-term tourism assets	BAM million (2015)	BHAS, n.d.	+
AVT	Added value in tourism value added	BAM million (2015)	BHAS, n.d.	n/a
AVPE	Added value in tourism divided by the number of employees.	BAM thousand (2015)	WTTC, 2024	n/a

Source: author's compilation

The following section presents the econometric framework of the study, including the model specification, data sources, and diagnostic procedures employed to examine the interdependencies between tourism value added, total investment in the tourism sector, and gross investment in long-term assets in Bosnia and Herzegovina.

The analysis applies the ARDL–ECM methodology, which allows for the simultaneous modelling of short-run dynamic adjustments and long-run equilibrium relationships among variables (Pesaran et al., 2001). This approach is particularly suitable for datasets comprising variables with mixed orders of integration, I(0) and I(1), without requiring them to be stationary at the same level. Another advantage of the ARDL–ECM framework lies in its efficiency when applied to shorter time series, which is highly relevant given that only 24 annual observations are available in this study. Moreover, the framework enables the inclusion of dummy variables representing structural breaks, thereby ensuring more consistent estimates under conditions of limited data (Kripfganz & Schneider, 2023).

The theoretical foundation of the research is grounded in models linking investment to economic growth in the tourism sector, assuming that tourism value added is a function of both aggregate and specific forms of investment, while accounting for the technological and structural parameters of the economy (Balaguer & Cantavella-Jordá, 2002). These models help to clarify how different categories of investment affect productivity and sectoral development over the long run. It is important to emphasise that the results are context-specific and pertain to the economy of Bosnia and Herzegovina, given its distinct institutional and macroeconomic characteristics.

The applied ARDL–ECM can be represented by the following equation:

$$\Delta \ln Y_i = \alpha_0 + \sum_{i=1}^{p} \beta_i \, \Delta \ln Y_{t-i} + \sum_{j=0}^{q_1} \gamma_j \, \Delta \ln \mathrm{TI}_{t-J} + \sum_{k=0}^{q_2} \delta_k \, \Delta \ln \mathrm{GI}_{t-k} + \varphi_1 \ln Y_{t-1} + \varphi_{21} \ln \mathrm{TI}_{t-1} + \varphi_{31} \ln \mathrm{gi}_{t-1} + \varepsilon_t \quad (1)$$

where Δ denotes the first-difference operator, and p, q_1 and q_2 represent the optimal lag lengths. Given that two models are being evaluated, the dependent variable Y in the first model represents value added in tourism (AVT), while in the second model it represents the productivity of workers in tourism (AVPE). The parameters β_i, γ_j and δ_k capture the short-run effects of past changes in the observed variables, while the long-run coefficients ϕ_i reflect the equilibrium relationships between their levels. The sign and magnitude of these coefficients indicate the existence and strength of a stable long-run equilibrium. Finally, ε_i denotes the stochastic error term, capturing the influence of factors not explicitly modelled in the specification.

Short-run adjustments were captured through an error-correction model (ECM):

$$\Delta Y_t = \beta_0 + \beta_1 \Delta \ln Y_{t-1} + \sum_{i=0}^{p} \beta_{2,i} \Delta \ln \mathrm{TI}_{t-1} + \sum_{i=0}^{q} \beta_{3,i} \Delta \ln \mathrm{GI}_{t-1} + \gamma \mathrm{ECM}_{t-1} + \varepsilon_t \quad (2)$$

where γ measures the speed of adjustment back to equilibrium.

Diagnostic checks included Breusch–Godfrey LM for serial correlation, Breusch–Godfrey- Pagan test for heteroscedasticity, Jarque Berra test for normality and CUSUM stability tests.

The Error Correction Model specification enables the estimation of short-run changes in tourism value added in response to investment, while simultaneously incorporating information on the long-run equilibrium among the variables. Through the coefficient associated with deviations from long-run equilibrium, the model quantifies the speed of adjustment, i.e. the rate at which tourism value added responds in order to return to a stable long-run relationship with total tourism investment and gross investment in long-term assets. This coefficient is commonly referred to as the error-correction term, and it is obtained as the coefficient on the residual from the long-run equilibrium relationship between tourism value added and investment. The coefficients of the short-run dynamics capture the immediate effect of changes in investment on tourism value added, while the long-run component ensures that these changes converge toward a stable long-term trend.

Prior to model estimation, the stationarity of the observed series was assessed. A graphical analysis suggested the presence of potential structural breaks, i.e. sudden shifts in the level of the series. To formally identify such breaks, the Bai–Perron test (Bai & Perron, 2003) was applied, which allows for the detection of multiple breaks and the determination of their exact timing. The identified breaks were incorporated into the model as dummy variables, thereby controlling for structural changes and improving the reliability of the ARDL/ECM estimations. Traditional unit-root tests, such as the ADF test, may yield imprecise results in the presence of structural breaks; therefore, the Perron test with an additive outlier (AO) specification (Perron, 1989) was employed, enabling the detection of abrupt, one-time shifts in the level of the series, including both trend and intercept components (Gujarati & Porter, 2009).

Although the ARDL–ECM methodology offers flexible parameterisation, it assumes the absence of endogeneity among regressors, which may be restrictive in the case of macroeconomic series, as TI and GI may simultaneously exhibit causal interactions with AVT. In this study, a maximum of one lag was applied due to the limited sample size, reducing the risk of over-parameterisation but constraining the model's ability to capture more complex dynamic patterns (Gujarati & Porter, 2009; Kripfganz & Schneider, 2023; Narayan, 2005; Pesaran et al., 2001). The study does not incorporate nonlinear transformations of investment variables, which remains a recommendation for future research. In particular, the nonlinear ARDL (NARDL) approach could be employed to test for asymmetric effects of investment changes and economic shocks (Shin et al., 2014).

Considering the objective of this study—to establish the basic empirical interdependencies and ensure comparability with prior research—the ARDL–ECM framework proves adequate for analysing the relationships between investment and tourism sector performance in Bosnia and Herzegovina. Future research is encouraged to extend the model by incorporating nonlinear transformations and longer time series, thereby examining the marginal contributions of investment across different phases of the economic cycle or under structural breaks (Shin et al., 2014).

5. Empirical results and discussion

This section presents the empirical results obtained from the estimation of the ARDL model, starting with descriptive statistics, followed by stationarity and cointegration testing, and finally the estimation of long-run and short-run coefficients. The empirical analysis proceeds in three steps: (i) stationarity testing using Perron unit-root tests with structural breaks, (ii) cointegration testing using the ARDL bounds approach, and (iii) estimation of long-run and short-run coefficients within the ARDL–ECM framework.

Table 2 reports the descriptive statistics for all variables. The data indicate moderate variability, while the minimum and maximum values do not suggest the presence of significant outliers.

Table 2: Descriptive statistics

	Mean	Std.Dev	Max	Min
lnAV	20.09981	0.262569	20.73332	19.65074
lnAVPE	8.982171	0.131684	9.331327	8.809116
lnGI	18.38767	0.218331	18.70662	17.84519
lnTI	19.36034	0.300438	19.89086	18.86183

Source: Authors' calculations

Potential structural breaks in the observed series were first identified through a visual inspection of their trajectories (Figure 1 and Figure 2), taking into account abrupt changes in trend or level. To precisely determine the years in which structural shifts occurred, the Bai–Perron test (Bai & Perron, 2003) was applied, enabling the detection of multiple breaks within time series data. The test results are presented in Table 3, including the F-statistics, critical values, and the years of the identified breaks for each of the analysed series. For each series, the Perron unit-root test allowing for a single break was employed, with the break year determined according to the observed shifts in the series.

Table 3: Results of the Bai–Perron test for structural breaks

Series	F-statistic	Critical Value	Break Date
LNAVT	28.39 / 19.03	8.58 / 10.13	2007 / 2021
LNTI	18.96 / 10.35	8.58 / 10.13	2009 / 2021
LNGI	10.55 / 35.23	8.58 / 10.13	2007 / 2021
LNAVPE	28.38 / 19.03	8.58 / 10.13	2008 / 2021

Note: all reported F-statistics are statistically significant at the 5% level.

Source: Authors' calculations

Based on the test results, it was observed that all series share a common structural break in 2021, while additional breaks differ across series (lnAVT in 2007, lnTI in 2009, lnGI in 2007, and lnAVPE in 2008). These findings confirm the preliminary observations from the graphical analysis, where abrupt changes in trend had already been visually detected. Given the identified breaks, stationarity was tested using the Perron test with an additive specification, which allows for the simultaneous modelling of level and trend shifts. This variant more accurately accounts for the consequences of breaks and better reflects the actual dynamics of the series, thereby increasing the reliability of stationarity assessment and facilitating the subsequent application of the ARDL/ECM framework. The test results are reported in Table 4.

Table 4: Unit root test

Variable	Break year	t - statistika	Critical value at 1%	Critical value at 5%	Conclusion
lnAVT	2007	-3.92053	-4.373333	-3.74667	significant at the 5% level
lnAVT	2021	-3.517669	-3.918333	-3.336667	significant at the 5% level
lnAVPE	2008	-2.747000	-4.352500	-3.730000	no significant
ΔlnAVPE	2008	-5.927899	-4.366087	-3.740870	significant at the 1% level
lnAVPE	2021	-3.725333	-3.918333	-3.336667	significant at the 5% level
lnTI	2009	-3.033606	-4.336667	-3.72667	no significant
ΔlnTI	2009	-6.449524	-4.344348	-3.723478	significant at the 1% level
lnTI	2021	-2.123406	-3.918333	-3.336667	no significant
ΔlnTI	2021	-5.692365	-3.929585	-3.346087	significant at the 1% level
lnGI	2007	-2.981125	-4.373333	-3.746667	no significant
ΔlnGI	2007	-4.624584	-4.387826	-3.758261	significant at the 1% level
lnGI	2021	-1.945826	-3.918333	-3.336667	no significant
ΔlnGI	2021	-13.44210	-3.295665	-3.346087	significant at the 1% level

Source: Authors' calculations

Table 4 presents the results of the Perron stationarity test for the four analysed series, taking into account the identified structural breaks. The results show that lnAVT is stationary at level (I(0)) in the identified break years, while the series lnAVPE, lnTI, and lnGI are non-stationary at level but become stationary after first differencing, confirming that these variables are integrated of order one, I(1).

The results of the Perron stationarity test therefore confirm different levels of integration across the observed series: while the model with lnAVT as the dependent variable and lnTI and lnGI as independent variables contains a combination of I(0) and I(1) series, the model with lnAVPE as the dependent variable comprises only I(1) series. Given these characteristics, as well as the relatively short sample period, the application of the ARDL/ECM model remains methodologically justified, as this approach allows for the simultaneous modelling of short-run and long-run relationships among variables of mixed or identical integration orders, while controlling for potential structural breaks.

In view of the limited number of annual observations, the maximum lag length in the ARDL model was restricted to one. To control for the effects of the identified structural breaks on the dependent variables, four dummy variables (d1–d4) were included in the model, defined as follows:

- **d1** denotes the break in 2007 (lnAVT and lnGI), taking the value 0 up to 2006 and 1 from 2007 onwards.

- **d2** refers to the 2008 crisis (lnAVPE and lnTI), taking the value 0 up to 2007 and 1 from 2008 onwards.

- **d3** captures the additional break specific to the lnTI series in 2009, taking the value 0 up to 2008 and 1 from that year onwards.

- **d4** denotes the common break in 2021 for all series, taking the value 0 up to 2020 and 1 from 2021 onwards.

The inclusion of these dummy variables is particularly important because the observed period includes two major external shocks that affected both investment behaviour and tourism performance. The global financial crisis of 2008–2009 reduced investment capacity, constrained access to finance, and slowed capital formation in tourism-related activities. In the context of Bosnia and Herzegovina, where tourism investment was already characterised by low capital intensity and fragmented institutional coordination, the crisis likely reinforced delays in fixed-asset investment and weakened the transmission of capital formation into productivity gains. The COVID-19 pandemic represented an even more direct shock to the tourism sector, as restrictions on mobility, the collapse of international travel, and temporary closures of accommodation and hospitality facilities sharply reduced demand and disrupted the utilisation of existing tourism capacities. The common structural break identified in 2021 therefore captures not only the immediate pandemic shock but also the post-pandemic adjustment phase, in which tourism activity began to recover while investment and productivity dynamics remained affected by uncertainty and uneven capacity utilisation.

The initial stage of the ARDL approach tests for the existence of a long-term relationship among the observed variables. The null hypothesis states that no cointegration relationship exists between the examined variables, regardless of whether the explanatory variables are purely I(0) or I(1). If the calculated F-statistic exceeds both the lower and upper bounds of the critical values, the null hypothesis is rejected. The results confirm the presence of cointegration between the variables, as the F-statistic exceeds the upper bound at all conventional significance levels (10%, 5%, and 1%). The results of the bounds test are presented in Table 5.

Table 5: Bounds test for cointegration

Model	Test statistic	Value	I(0)	I(1) Bound	Conclusion
Model 1 - AVT	F statistics	17.732154	5.155	6.265	Cointegration exists at the 1% significance level
Model 2 - AVPE	F statistics	17.201656	5.155	6.265	Cointegration exists at the 1% significance level

Source: Authors' calculations

The long-term ARDL estimates are summarized in Table 6.

Table 6: Long-run estimates of the ARDL model

Variable	Coefficient	Std. Error	t-statistics	Significance
Model 1 – lnAVT				
lnAVT(-1)	-0.504207	0.236598	-2.131071	*
lnTI	0.232185	0.097901	2.371625	*
lnGI	1.355748	0.252934	5.360091	***
d1	-0.042610	0.055810	-0.763493	not significant
d3	0.058436	0.049794	1.173564	not significant
d4	0.952701	0.140891	6.761950	***
C	0.660562	2.257190	0.292648	not significant
Model 2 – lnAVPE				
lnAVPE(-1)	-0.289971	0.157447	-1.841712	*
lnTI	-0.319439	0.082393	-3.877036	***
lnGI	0.826245	0.148382	5.568355	***
lnGI(-1)	-0.136402	0.079954	-1.706011	not significant
d2	0.017546	0.054730	0.320592	not significant
d3	0.079761	0.050322	1.585012	not significant
d4	0.644778	0.119195	5.409458	***
C	4.932142	2.328447	2.118211	*

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, no significance $p > 0.1$

Source: Authors' calculations

As shown in Table 6, the long-run coefficients in both models follow different patterns. The results indicate that investment in long-term assets has a significant positive effect in the long run on both tourism value added and labour productivity in tourism. Specifically, a one-percent increase in GI leads to a 0.83% rise in AVPE and a 1.36% rise in AVT, suggesting that investment in long-term assets constitutes the main driver of growth and productivity in the tourism sector.

The results also show that total investment in the tourism sector exerts different effects across the two models. In the AVT model, TI positively influences tourism value added, whereas in the AVPE model, TI negatively affects labour productivity. The finding that total tourism investment has a negative long-run effect on labour productivity calls for deeper interpretation and points to structural weaknesses in the tourism sector in Bosnia and Herzegovina. One possible explanation is the "labour absorption" effect, whereby investment-driven expansion generates additional employment, primarily seasonal and low-skilled, which reduces value added per employee even though the sector's overall output increases. In addition, inefficient capital allocation—predominantly into small guesthouses, seasonal facilities, and low-productivity segments—expands the sector without substantially improving efficiency. A similar effect arises from pronounced fragmentation and seasonality: more than 70% of overnight stays are concentrated in three destinations and in the summer quarter, meaning that investments are not evenly utilised throughout the year and do not promote diversification of supply. This interpretation is consistent with Niavis and Kallioras (2021), who show that seasonality and spatial concentration of tourist flows affect tourism-sector efficiency in a non-linear manner, implying that concentration of demand may reduce efficiency when it leads to uneven capacity utilisation and limits the diffusion of tourism benefits across regions. Finally, institutional factors, such as complex regulatory procedures and the lack of strategic guidance, may cause investments to assume a rent-seeking character, directed more toward short-term subsidies and opportunistic projects than toward long-term sustainable productivity. These results suggest that the quantity of investment alone is insufficient; rather, its quality, structure, and the institutional framework in which it is implemented are decisive.

The coefficients of the lagged dependent variables (lnAVT(–1) and lnAVPE(–1)) are statistically significant and negative, confirming a process of partial adjustment toward long-run equilibrium. Among the dummy variables representing structural breaks, only the variable associated with the COVID-19 crisis shows a statistically significant effect. This suggests that the pandemic shock had a stronger and more persistent effect on tourism value added and labour productivity than the earlier financial crisis, most likely because COVID-19 directly disrupted mobility, accommodation demand, and capacity utilisation in the tourism sector.

Finally, the constant term in the AVPE model is significant at the 10% level, whereas in the AVT model it is not, suggesting that unobserved factors may influence productivity more strongly than overall tourism value added. Overall, the results indicate that investment in long-term assets plays a crucial role in driving growth and productivity in the tourism sector, while the COVID-19 pandemic had a significant impact in both models.

All diagnostic tests confirm that the ARDL model is statistically well-specified. The results of these tests are presented in Table 7 and Table 8.

Table 7: Diagnostic tests for Model 1

Test	Statistic	*p*-value	Conclusion
Serial Correlation (LM)	0.751830	0.4898	No serial correlation
Heteroscedasticity (BP-G)	1.196852	0.3571	No heteroscedasticity
Normality (Jarque – Bera)	3.256743	0.19655	Residuals normal
Stability (CUSUM)	-	-	Stable model

Source: Authors' calculations

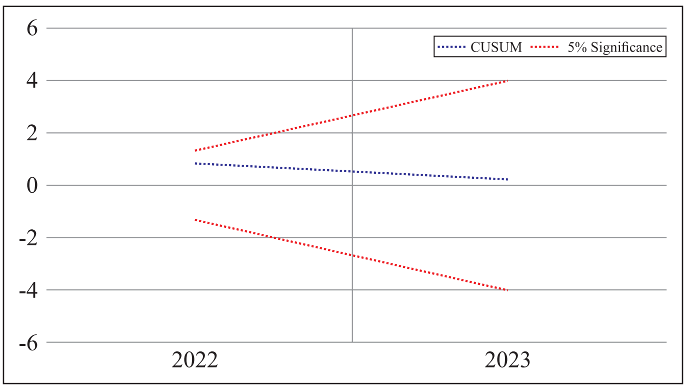
Table 8: Diagnostic tests for Model 2

Test	Statistic	p-value	Conclusion
Serial Correlation (LM)	0.567058	0.5806	No serial correlation
Heteroscedasticity (BP-G)	0.7775	0.0700	No heteroscedasticity
Normality (Jarque – Bera)	1.233873	0.539595	Residuals normal
Stability (CUSUM)	-	-	Stable model

Source: Authors' calculations

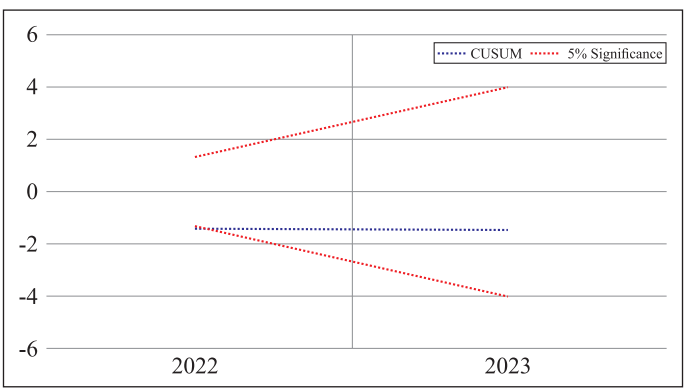
The diagnostic tests indicate that both ARDL models are statistically well-specified, with no evidence of serial correlation and with residuals following a normal distribution. The CUSUM plots further confirm the stability of the models over the observed period, as presented in Figures 3 and 4.

Figure 3: Coefficient stability (CUSUM) – Model 1



Source: Authors' calculations

Figure 4: Coefficient stability (CUSUM) – Model 2



Source: Authors' calculations

The results of the ECM model presented in Table 9 for short-run dynamics show that changes in current tourism investment (ΔlnTI) and investment in long-term assets (ΔlnGI) generally do not exert statistically significant effects on tourism value added or labour productivity in the sector. However, in the labour productivity (AVPE) model, a positive effect of long-term investment is observed at the 10% significance level, suggesting that even in the short run certain investment changes may contribute modestly to improvements in workforce efficiency. This indicates that the sector possesses mechanisms for partial transmission of investment effects onto productivity, although overall short-run impacts remain limited.

Table 9: Short-term coefficients and ECM

Variable	Coefficient	Std. Error	t - statistics	Significance
Model 1 – AVT				
ΔlnTI	0.353797	0.245996	1.438277	not significant
ΔlnGI	0.229620	0.163230	1.406731	not significant
ECM(-1)	-0.607776	0.2759880	-2.202182	**
c	0.022820	0.026226	1.438227	not significant
Model 2 –AVPE				
ΔlnTI	-0.110257	0.199423	-0.552879	not significant
ΔlnGI	0.217088	0.110664	1.961683	*
ECM(-1)	-0.593935	0.210606	-2.820120	***
c				

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, no significance $p > 0.1$

Source: Authors' calculations

The error-correction coefficient (ECT) is –0.61 and statistically significant, indicating that the sector tends to return to its long-run equilibrium after deviations. Approximately 61% of the divergence from the long-run relationship between investment and tourism value added in the previous year is corrected in the current year. The economic implication of this finding is that, although short-run investment effects are weak, an automatic adjustment mechanism enables a gradual return to a stable long-term path, contributing to the resilience of tourism against external and internal shocks. In the second model, the speed of adjustment is similar, at around 60%.

Given the relatively short time series (2000–2023) and the presence of several structural breaks, the econometric results should be interpreted with caution. The limited length of the dataset reduces the statistical power of asymptotic tests, which is explicitly acknowledged as a methodological limitation.

Although alternative proxies for tourism development, such as tourism receipts, could provide additional insights into the investment–performance relationship, the availability of consistent and sufficiently long time-series data for Bosnia and Herzegovina remains limited. In this context, tourism value added represents a more comprehensive and methodologically consistent measure, as it captures both direct and indirect contributions of the sector. Future research could extend the present analysis by testing the robustness of the results using alternative indicators of tourism performance, including disaggregated revenue-based measures. Moreover, AVT is less sensitive to short-term demand fluctuations and therefore better captures long-run structural effects of investment.

The findings confirm that both total tourism investment and investment in long-term assets have a significant positive effect on tourism value added in the long run, while short-run effects are statistically insignificant. This result is consistent with theoretical assumptions about capital deepening and demonstrates that the impacts of investment materialise only after a certain time horizon, once new capacities and infrastructure become operational. At the same time, the functionality of the error-correction mechanism (ECM) confirms that deviations from the equilibrium path are corrected, underscoring the stability of long-run relationships between investment and sectoral performance.

The most interesting and unexpected result is that total tourism investment has a negative long-run effect on labour productivity. This paradoxical outcome suggests that while overall investment contributes to sectoral value added, it simultaneously reduces value added per worker, likely reflecting labour market weaknesses and inefficient capital allocation in Bosnia and Herzegovina. Possible explanations include pronounced seasonality and spatial concentration of demand, the expansion of low-skilled and seasonal employment that dilutes per-worker productivity, and investments directed towards facilities and segments with lower efficiency. These findings suggest that the quantity of investment is not sufficient; rather, the quality and structure of investment are decisive.

This result can be related to the available regional literature. Ivanovic et al. (2011) show that foreign direct investment has contributed to tourism development in Croatia, while Perić and Nikšić Radić (2015) find a positive relationship between tourism FDI and tourism productivity. In addition, Gričar et al. (2021) emphasise the importance of labour productivity dynamics in the tourism sectors of Croatia and Slovenia. Against this background, the findings for Bosnia and Herzegovina refine the regional evidence by showing that not all forms of investment generate the same productivity effects. While gross investment in long-term assets has a positive long-run effect on both tourism value added and labour productivity, total tourism investment has a negative long-run effect on AVPE. This suggests that productivity gains depend less on the aggregate volume of investment and more on its structure, quality and allocation.

This finding also represents the main point of departure from much of the existing tourism-investment literature. While previous studies generally associate tourism investment with productivity improvements, the results for Bosnia and Herzegovina show that the aggregate volume of investment does not automatically translate into higher labour productivity. The negative long-run effect of total tourism investment on AVPE suggests that investment may expand sectoral output and employment while simultaneously diluting productivity if it is directed toward low-efficiency activities, seasonal facilities, or fragmented small-scale projects. In contrast, the positive effect of GI confirms that fixed-asset investment and capital deepening are more closely linked to productivity-enhancing capacity. The contribution of this paper therefore lies in showing that the type and structure of investment matter more than investment volume alone in a data-constrained post-transition tourism economy.

This study is subject to several limitations that should be considered when interpreting the empirical findings. First, the analysis is based on a relatively short annual time series (2000–2023), which limits the statistical power of econometric tests and constrains the complexity of model specification. Second, the presence of multiple structural breaks, particularly those associated with the global financial crisis and the COVID-19 pandemic, introduces additional instability that cannot be fully captured despite the use of dummy variables. Third, due to data limitations, the analysis does not distinguish between different sources of investment, such as public, private, or foreign direct investment, which may have heterogeneous effects on productivity. Fourth, potential endogeneity between investment and tourism performance cannot be entirely ruled out within the applied ARDL–ECM framework. Finally, the model does not incorporate nonlinear or asymmetric effects of investment, which may be relevant in the context of economic shocks and structural transitions. Despite these limitations, the model provides consistent and interpretable estimates that contribute to understanding the investment–productivity relationship in a data-constrained transition economy.

6. Conclusions

This study provides a detailed analysis of the effects of investment on tourism performance in Bosnia and Herzegovina, focusing on total tourism investment and gross investment in long-term assets. The empirical results, obtained using the ARDL–ECM model, show that investment in long-term assets plays a crucial role in increasing overall tourism value added and labour productivity. Specifically, a 1% increase in gross investment in long-term assets leads to a 1.36% rise in tourism value added and a 0.83% rise in labour productivity, confirming the importance of capital deepening for the sector's sustainable growth.

In contrast, total tourism investment exhibits a paradoxical effect: while it contributes to overall sectoral expansion, it negatively affects labour productivity, pointing to structural constraints such as pronounced seasonality, spatial concentration of demand, the prevalence of low-skilled and seasonal workers, and inefficient capital allocation. Short-run investment effects are limited, yet the error-correction mechanism demonstrates that deviations from long-run equilibrium adjust at a rate of approximately 60% annually, indicating sectoral resilience.

The empirical results confirm the hypothesis regarding the positive long-run effect of long-term asset investment on both tourism value added and productivity, while total investment in tourism exerts a paradoxical negative effect on labour productivity. These findings highlight that the quantity of investment is not sufficient; rather, the quality, structure, and institutional framework within which investment is realised are decisive.

The findings carry practical implications for policy design. First, investment strategies should prioritise the quality and structure of capital formation rather than the aggregate volume of investment alone. This implies a stronger focus on fixed-asset investment, infrastructure upgrading, digitalisation, and capacity modernisation that directly enhance productivity. Second, public incentive schemes should be designed to favour projects with clear productivity-enhancing effects, such as year-round accommodation capacity, higher value-added tourism products, workforce training, and destination-level infrastructure. Third, policymakers should address seasonality and spatial concentration by supporting investment in underutilised destinations, thematic tourism products, and integrated destination management systems that extend demand beyond peak periods and dominant urban or coastal centres. Finally, public–private partnerships and targeted financing instruments could help overcome fragmented project pipelines and improve the allocation of capital toward long-term tourism competitiveness.

Future research should pursue more detailed micro-level analyses, including the effects of investment on firm-level productivity, differentiating between types of tourism businesses (e.g., hotels, rural tourism) and categories of employees. Comparative studies with other post-transition economies in the region may further clarify the role of structural and institutional factors in shaping investment efficiency. Incorporating qualitative assessments of governance, regulatory frameworks, and strategic planning could also explain discrepancies between investment volume and productivity outcomes.

Overall, the study demonstrates that investment-driven tourism growth can improve sectoral performance and productivity, but only when accompanied by structural improvements, strategic planning, and targeted capital allocation. Notwithstanding these limitations, the results provide consistent and policy-relevant evidence on the role of investment in shaping tourism productivity in Bosnia and Herzegovina. Future research should extend the sample, apply alternative specifications such as nonlinear or panel ARDL models, and test for asymmetric effects of investment shocks.

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Utjecaj investicija na produktivnost i razvoj turizma u Bosni i Hercegovini

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Sažetak

Rad analizira kratkoročne i dugoročne učinke ulaganja na dodanu vrijednost turizma i produktivnost rada u Bosni i Hercegovini u razdoblju 2000. – 2023. Ulaganja se promatraju kroz dvije kategorije: ukupna ulaganja u turizam i bruto ulaganja u dugotrajnu materijalnu imovinu. Rezultati pokazuju da dugoročna ulaganja u fiksnu imovinu imaju statistički značajan pozitivan učinak na dodanu vrijednost turizma i produktivnost rada. Naime, povećanje bruto ulaganja u dugotrajnu imovinu za 1 % povećava dodanu vrijednost turizma za 1,36 %, a produktivnost rada za 0,83 %. Nasuprot tome, ukupna ulaganja u turizam imaju dvojak učinak: iako pozitivno djeluju na dodanu vrijednost turizma, istodobno negativno utječu na produktivnost rada, što upućuje na paradoks prema kojem rast sektora ne rezultira nužno većom produktivnošću po zaposlenom. Uzrok ovakvog učinka može biti u strukturnim ograničenjima, odnosno u sezonalnosti, prostornoj koncentraciji potražnje, prevladavanju niskokvalificiranog i sezonskog rada te neučinkovitoj alokaciji kapitala. Kratkoročni učinci su ograničeni, no mehanizmi korekcije pogreške potvrđuju stabilno prilagođavanje dugoročnoj ravnoteži, a godišnje usklađivanje korigira oko 60 % odstupanja. Rezultati analize naglašavaju važnost kontinuiranih ulaganja u dugotrajnu imovinu i kapitalnog produbljivanja, kako bi doprinijeli rastu ukupnog outputa turizma i produktivnosti rada, dok istodobno upućuju na to da samo ulaganje nije dostatno bez rješavanja strukturnih i institucionalnih ograničenja.

Ključne riječi: *ulaganja u turizam, produktivnost, kointegracija, Bosna i Hercegovina, dugotrajna imovina*

JEL klasifikacija: *O47, C32, Z32*

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Determinants of ICT Adoption and the Fourth Industrial Revolution in the EU*

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Abstract

Information and communication technology (ICT) is transforming the world and rapidly reshaping both the economy and the society. It is a central driver of the Fourth Industrial Revolution (4IR), a new paradigm of digital transformation, industry, and technological development. Within the European Union (EU), the 4IR has become a strategic priority aimed at reducing the competitive gap with its most important rivals, such as the United States of America and China. This research seeks to increase the knowledge and deepen the understanding of ICT and the 4IR, as well as their drivers. The key objective is to identify the determinants of ICT adoption and the 4IR in the EU during the period 2012-2019. To achieve this, a two-step dynamic panel generalized method of moments (GMM) estimator was used. The main findings indicate that foreign direct investment, institutional framework, economic growth and globalization are all positively and statistically significant associated with ICT adoption and the 4IR. Given that ICT and the 4IR represent crucial engines and strategic priorities of EU and global development, EU policy makers should be focused on the creation of a macroeconomic and political environment that will encourage digital transformation and a faster adoption of ICT.

Keywords*: information and communication technology, the Fourth Industrial Revolution, European Union, generalized method of moments*

JEL classification*: O30, O10, F63, L52*

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1. Introduction

Information and communication technology (ICT) is a revolutionary technology that leads to rapid technological and economic developments by fostering globalization and international cooperation. It drives the Fourth Industrial Revolution (4IR), a creative destruction process that causes substantial disruptions across all segments of the global economy and society. Roser et al. (2024) state that technological changes, industrial revolutions, and innovations such as ICT have significantly improved living standards and positively affected economic and social development. Philbeck and Davis (2019) note that each industrial revolution represents a technological change that causes significant disruptions and reshapes the society. Horowitz (1964) emphasizes the need to examine various economic and social aspects of industrial developments and their determinants, beginning with the First Industrial Revolution. Wisman and Capehart (2010) refer to Schumpeter and his idea that industrial revolutions represent creative destruction processes that enabled capitalism to become the most effective economic system for increasing living standards and productivity. According to Krapež et al. (2015), the 4IR began in 2011 as a new paradigm aimed at enhancing the competitiveness of Germany and the EU and advancing industrial digitalization.

Pena-Cabrera et al. (2019) note that although the 4IR, driven by ICT, is a major phenomenon that affects all segments of society and transforms it into Society 4.0, it remains understudied, particularly regarding its impacts and drivers. ICT-based technologies spread rapidly, providing significant opportunities for social and economic development and paving the way toward the Fifth Industrial Revolution (5IR), whose key driver is also ICT. Sarfraz et al. (2021) confirm that the 4IR forms the foundation not only for the 5IR, but also for Society 5.0, as both build upon the 4IR technologies. The 5IR is human-centered and more focused on the interdependence between people and machines. The Covid-19 pandemic, which caused the fastest pace of digitalization in human history, was the main driver of transformation from the 4IR to the 5IR. Noble et al. (2022) state that the 5IR focuses on the interaction between humans and machines, as well as on sustainable and inclusive development that benefits multiple stakeholders, including companies, customers, workers and society as a whole. There are certain differences among the 4IR and the 5IR. While the 4IR is focused on technological potential, the 5IR seeks to maximize the potential of people and technology working collaboratively, rather than competitively. Szeszák et al. (2025) argue that the 5IR represents a new technological paradigm in the EU, as the European Commission has identified it as strategic priority. It marks a transformation from a technology-focused to a more human- and sustainability-focused concept. As an evolution of the 4IR, it emphasizes the role of technology in encouraging creativity, promoting ethical behavior and strengthening economic resilience. Laffi and Lenzi (2021) identify ICT as the primary driver of the 4IR, alongside innovation and human capital, and emphasize the need for further research due to a lack of relevant cognitions.

Walsham (2017) explains that ICT remains a new and understudied topic that requires more scientific research, with a particular focus on its impacts on the economy and society and its determinants, given its rapid global diffusion and variety of benefits. The topic also requires an interdisciplinary approach. Duque et al. (2007) support this view, stating that ICT is a crucial globalization and development engine that started to evolve during the Cold War as a scientific and government project, but it spread rapidly throughout the society. Vežić et al. (2022), using panel regression, confirm the importance of ICT in building high-quality human capital, which is a key development engine in high-, middle- and low-income economies.

The research problem addressed in this study concerns the knowledge gap related to understudied topics such as ICT, the 4IR and its determinants. The lack of research on these topics is also confirmed by Walsham (2017) and Pena-Cabrera et al. (2019). The 4IR has been established as a key development strategy of the EU. As confirmed by the European Parliament (2016) and the European Institute of Innovation & Technology (2021), ICT adoption, diffusion and digitalization are the European future and present. The main objective of this research is to identify the main determinants of ICT adoption and the 4IR in the EU during the period 2012-2019.

To achieve this objective, the following research questions were formed:

> RQ1: *How is the institutional framework associated with ICT adoption and the 4IR?*
>
> RQ2: *How is globalization associated with ICT adoption and the 4IR?*
>
> RQ3: *How is foreign direct investment (FDI) associated with ICT adoption and the 4IR?*
>
> RQ4: *How is economic growth associated with ICT adoption and the 4IR?*

Hypotheses set in this research are:

> H1: *The institutional framework is positively and significantly associated with ICT adoption and the 4IR.*
>
> H2: *Globalization is positively and significantly associated with ICT adoption and the transition toward the 4IR.*
>
> H3*: FDI is positively and significantly associated with ICT adoption and the 4IR.*
>
> H4: *Economic growth is positively and significantly associated with ICT adoption and the 4IR.*

The paper is structured into six sections. The first section provides a brief introduction to the research topic and outlines the research problem, objectives, questions and hypotheses. The second section comprises theoretical background. Methodology is explained in the third section, while the fourth section explains the data and variables used in the model. The results of the model and the discussion are provided in the fifth section. The last, sixth section offers concluding remarks.

2. Literature review

McKinsey (2022) defines the 4IR as a new era in the digitalization of industry and production. It represents a continuation of the previous ICT revolution, driven by ICT-based technologies such as artificial intelligence (AI), blockchain, the Internet of things, big data, smart systems and virtual reality. Chou (2018) describes the 4IR as a major paradigm shift caused by the rapid diffusion of ICT and scientific progress. According to the National Institute for Standards and Technology (2024), ICT is a state-of-the-art widespread technology that encompasses various hardware and software elements, the purpose of which is a faster and a more efficient information collection, storage, exchange and processing.

Previous research, including Castelo-Branco et al. (2022) and Karabegović (2017), identifies ICT and digital infrastructure as the most important indicators and drivers of the 4IR. Other key drivers include knowledge, skills and education level, innovation, managerial practices, and adaptability. Muscio and Ciffolilli (2019) argue that the 4IR remains a highly understudied topic and define it as an innovation in technologies, manufacturing and business operations, characterized by rapid digital transformation and the usage of disruptive technologies and paradigms, such as smart systems. The 4IR is also an EU strategic priority. Its drivers include investments in research and development (R&D), cooperation among private, educational, academic and public sectors, regional collaboration, educational attainment and the share of the workforce employed in the production sector. Broz et al. (2020) find that digital transformation, which is based on ICT and encompasses the 4IR, affects society as a whole and stimulates economic growth, FDI and trade. Milošević et al. (2018) confirm this and state that EU countries differ in the ICT adoption and adjustment to the 4IR, and that economic development and human capital are key drivers of ICT adoption.

Weber and Kaufman (2011) identify multiple economic, technological and social drivers of ICT adoption at the company, industry, national and global levels, including economic activity and growth, living standard, globalization, institutional and legal framework, political environment, innovation capacity, human capital, and technological development. ICT increases productivity and causes significant cultural changes. Chinn and Fairlie (2006) state that institutional quality, such as the initial condition of ICT infrastructure, living standards and human capital, is the most important factor explaining differences in ICT adoption across low-, middle- and high-income economies. Krüger and Rhiel (2016), using principal component analysis on 178 countries (including the EU) in the period 1990-2014, confirm that the main drivers of ICT adoption and the 4IR are living standards, institutional framework, access to electricity and urbanization level. FDI and gross domestic product (GDP) also affect ICT adoption, but their impacts might be questionable.

The OECD (2023) states that FDI plays a crucial role in developing key infrastructure, particularly ICT, in both developed and developing countries. Shahbaz et al. (2022) find that FDI is a significant driver of the 4IR, alongside the institutional framework, financial and banking sector quality, export structure, and living standards, based on a panel of seven countries from 2000 to 2018. Shirazi et al. (2010) note a lack of extensive and systematic research on the effects of FDI on ICT. Using a panel of 17 Asian economies between 1996 and 2005, they found FDI positively affects ICT in the East Asian economies, but negatively in the MENA region. Besides FDI, other important determinants of ICT adoption include GDP growth, human capital, trade liberalization, institutional framework and urbanization. Gholami et al. (2006) confirm a lack of relevant literature that examines correlation among FDI and ICT, especially the impact of FDI on ICT. On a panel of 23 national economies between 1976 and 1999, they found that FDI contributes to better ICT infrastructure and faster adoption, especially in developing countries, and the relationship is bidirectional. Schäfer (2018) argues that the 4IR, driven by R&D and high technologies like ICT, represents a major opportunity for the EU, and that investment activity, particularly FDI, should be a central driver of the 4IR alongside the institutional framework and EU policies.

A crucial problem in the relevant literature is a lack of systematic research on the influence of GDP growth on ICT and the 4IR. Researchers mostly examine the reverse correlation, as confirmed by Broz et al. (2020), or bidirectional causality. Veeramacheneni et al. (2007) argue that the correlation among FDI, ICT and economic growth is an understudied topic and that the examination of this correlation represents an important scientific interest. Using Granger causality tests for 10 Latin American countries in the period 1975-2003, they confirmed that the correlation among FDI, economic growth and ICT differs. In seven out of ten countries there is a strong statistically significant bidirectional causality between ICT adoption and economic growth, while significant effect of economic growth on ICT adoption is found in two observed economies. FDI is confirmed as an important determinant of ICT adoption. Banerjee et al. (2019) also found that there is a bidirectional causality and a strong impact of economic growth on ICT infrastructure and adoption using the Granger causality test on a panel on 107 developed, emerging and transition countries, including the EU, in the period 2008-2017. Koutroumpis (2009) used the macroeconomic production function with a micro-model for ICT on 22 OECD economies between 2002 and 2007. It was found that economic growth and human capital are key drivers of ICT adoption, while investments in R&D are insignificant. Using a panel and the Granger causality test for European countries in the period 1960-2016, Pradhan et al. (2019) confirm an important and bidirectional causality among ICT, economic growth and innovation, although the impact varies depending on other factors, such as the institutional framework and human capital. Economic growth and innovation activity are therefore two important drivers of ICT adoption and the 4IR.

Bakay et al. (2010) identify globalization is an important determinant of ICT adoption. Using a panel of Latin American countries in the period 2002-2008, they find that the determinants of ICT adoption are economic growth, human capital, urbanization, investments in ICT and inequality. Zahid et al. (2018) emphasize the scarcity of quality research examining the importance of economic growth, FDI and globalization for ICT adoption. Using a panel and principal component analysis on BRICS economies between 2000 and 2014, they confirm bidirectional causality among globalization, and ICT adoption and the 4IR, as well as FDI and economic growth. Škare and Riberio Soriano (2021), using a panel of 183 countries, including the EU, confirm globalization as a key factor for ICT adoption and the 4IR. Another important determinant is overall national competitiveness, measured by the Global Competitiveness Index, which includes political, economic, social, cultural and innovation environments. International Monetary Fund (2018) also confirms that globalization and economic growth drive ICT adoption and the 4IR on the global level. Camilla et al. (2013) confirmed on a panel of EU economies in the period 1970-2004 that globalization is a key driver of ICT adoption, technological development and the 4IR, primarily through its drivers, such as FDI and trade. Goldberg et al. (2010) confirm similar findings not only for the EU, but also for all European and Central Asian countries. Sart et al. (2022), using cointegration tests, found that ICT and globalization have positive effects on educational attainment, but also that there is strong bidirectional causality between ICT adoption and globalization in New Europe economies in the period 2000-2018.

Baccianti et al. (2022) find that institutional framework, particularly government effectiveness, and globalization are crucial determinants of ICT adoption and the 4IR in 101 national economies across the world in the period 1996-2019, with a special focus on EU economies. International Telecommunication Union (2021), examining 145 economies in the period 2008-2019, confirms that institutional framework and government effectiveness play key roles in ICT adoption and the 4IR. King et al. (1994) state that institutional quality represents a crucial driver of ICT adoption. Political institutions have the strongest impact because government effectiveness affects ICT through knowledge development, human capital, creation of a macroeconomic framework for ICT adoption, and trade and investment liberalization, while certain top-down policies can have a limited or negative impact on the ICT. Kiessling (2006), using a panel of 82 developed, emerging and transition economies, including the EU, states that institutional framework and government effectiveness positively affect ICT adoption, while another important driver is also the quality of financial and economic institutions. Living standards and human capital similarly exert positive effects on ICT adoption.

3. Methodology and conception of analysis

ICT is a key driver of economic and societal progress. Relevant literature, including Walsham (2017) and Muscio and Ciffolilli (2019), emphasizes that ICT and the 4IR, particularly their determinants, remain understudied, despite their substantial impacts on the economy and society. The EU defines ICT as its strategic priority since it is a key indicator and driver of the 4IR that is set as key EU development and technological strategy to reduce the competitive gap with major global rivals. Although various determinants affect ICT adoption and the 4IR, as mentioned previously, they remain insufficiently explored. Equation 1 presents the dependent and independent variables included in the model.

$$ICT = f(FDI_{i,t};\ inst_{i,t};\ GDPgro_{i,t};\ KOF_{i,t};\ gov_{i,t}) \quad (1)$$

A two-step dynamic panel generalized method of moments (GMM) estimator is used as the methodological approach for this research. As noted by Shahbaz et al. (2022), this method is appropriate for examining correlations among variables such as those analyzed in this paper. Kiviet et al. (2017) confirm that GMM is widely used. It enables the explanation of empirical situations where heterogeneity is not determined and is affected by the regressors in the model. Its advantages include robustness, simplicity, accuracy and suitability for explaining general empirical patterns. Youssef et al. (2014) highlight that GMM improves estimator accuracy and efficiency, while Ahn and Schmidt (1995) confirm its asymptotic efficiency. Syofya (2022) notes that this method is suitable for examining correlations among independent and dependent variables, since it examines dynamic relationships among them and enables the usage of lagged dependent variables. Hansen (1982) and Piper (1982) argue that the usage of this method ensures model stability, accuracy, and asymptotic distribution of normality, making it appropriate for hypothesis testing coefficient estimation. Hsiao (1985; 2020) states that GMM effectively mitigates bias arising from omitted variables and enhances model efficiency by improving accuracy and relevance of results. It also addresses multicollinearity in explaining specific effects of every independent variable in the model. According to Farzana et al. (2024), dynamic panel GMM should be used when the number of units is bigger than the number of time periods. This is the case in the present study (216>8), and the autoregressive nature of the components further supports the use of the dynamic panel approach. Both system GMM and difference GMM are suitable for models with a smaller number of time periods and a higher number of observations and both use the first differences, as confirmed by Bun and Windmeijer (2007). However, Blundell and Bond (1998) show that system GMM generally achieves a higher level of accuracy than difference GMM, particularly for first-difference variables and in the presence of potential biases.

These methodological advantages justify the use of GMM in this research. Since this study examines the topic that is understudied and includes multiple units, the use of a method which is robust and accurate was essential. Due to aiming to produce evidence-based policy recommendations, it is important that the method contributes to explaining situations in general. Furthermore, ICT adoption and the 4IR are impacted by multiple determinants, and since GMM eliminates the effects of biases and omitted variables, this is an additional reason why it was used. The data used in this study are non-stationary and the value of the dependent variable in the current year is determined by its value in the previous year.

This research aims to identify the determinants of ICT adoption and the 4IR in the EU during the period 2012-2019. This period is selected because, as noted by Krapež et al. (2015), the 4IR began in 2011, with its first measurable impacts expected in the following year, which is the first one in the model. According to Noble et al. (2022), 2020 marks the beginning of the 5IR. The model includes 162 observations. Although it cannot confirm bidirectional causality, the focus of the study is on identifying the determinants and drivers of ICT adoption and the 4IR, rather than on assessing the effects of ICT on other indicators.

Equation 2 presents a dynamic model with a single time-changeable lagged variable, where y_{it} represents the dependent variable in period t; y_{it-1} is the dependent variable with one period lag from t; u_i represents particular time-invariant effects and v_{it} represents the error term.

$$y_{it} = \beta y_{it-1} + u_i + v_{it}, \ |\beta| < 1 \tag{2}$$

Individual effects are treated as stochastic. Further significant suppositions related to the invariance of the model are errors v_{it} that are serially uncorrelated. Individual time-invariant effects are mostly related to previous effects of the dependent variable in the model, which indicates the problem of endogeneity. The econometric model used to address this issue is presented in Equation 3.

$$ICT_{i,t} = \beta_0 + \beta_1 FDI_{i,t} + \beta_2 inst_{i,t} + \beta_3 GDPgro_{i,t} + \beta_4 KOF_{i,t} + \beta_5 gov_{i,t} + u_{i,t} + v_{i,t} \tag{3}$$

This chapter has presented and explained the methodology and the initial model used to test the hypotheses. The next section provides a detailed explanation of the dependent and independent variables, such as diagnostics related to model consistency.

4. Empirical data and analysis

This research examines the association of economic growth, institutional framework, FDI and globalization with ICT adoption and the 4IR. The data, variables, and corresponding databases used for the purposes of this research can be found in Table 1. The selection of indicators is based on the relevant literature. Below the table, the rationale for including each variable and the justification for the chosen indicators are explained.

Table 1: Data and variables in the model

Symbol	Variable	Explanation	Database
d_ICT	ICT adoption and the 4IR	ICT infrastructure	World Intellectual Property Organization (WIPO) – Global innovation index (2024)
d_FDI	FDI	FDI inward flow as percentage of global FDI	UNCTAD (2024)
d_inst	Institutional framework	Institutions	World Intellectual Property Organization – Global innovation index (2024)
d_GDPgro	Economic growth	GDP annual growth (%)	World Bank (2024b), World Development Indicators
d_KOF	Globalization	Globalization index	KOF Swiss Economic Institute Globalization Index (2024)
d_gov	Institutional framework	Government effectiveness estimation	World Bank (2024c) – Worldwide Governance Indicators

Source: Author's calculations

The dependent variable in the model is d_ICT, chosen as a proxy for ICT adoption and the 4IR. The values of this indicator range from 0 (minimum) and 100 (maximum). It was set as dependent variable because ICT and the 4IR are understudied topics, as emphasized by Pena-Cabrera et al. (2019) and Walsham (2017). In addition, the main research objective is to identify the determinants of ICT adoption and the 4IR in the EU27, given that the European Parliament (2016) and the European Institute of Innovation & Technology (2021) identify ICT and the 4IR as EU strategic priorities aimed at reducing the gap with major competitors. There are certain reasons why this indicator was used as a proxy not only for ICT adoption but also for the 4IR. It is a very comprehensive indicator that captures all aspects of ICT and its adoption that drive the 4IR: ICT access, usage, online public services and e-participation of citizens. Relevant literature such as Castelo–Branco et al. (2022) and Karabegović (2017) identifies ICT as a key indicator of the 4IR, while McKinsey (2022) notes that the 4IR is built upon ICT-based technologies and represents a continuation of the previous ICT revolution.

Two indicators are used as proxies for the institutional framework: d_inst and d_gov. The d_inst variable measures the quality of the overall institutional environment, including regulatory quality, quality of the business environment, rule of law, and business policies. The values of this indicator range from 0 (minimum) to 100 (maximum). The d_gov variable or government effectiveness estimate measures the opinions of citizens about the civil and the public sector, its independence, quality, and efficiency of government policies and their implementation. The minimum value of this indicator is -2,5, while the maximum is 2,5. These indicators are used due to relevant literature, such as Baccianti et al. (2022) and International Telecommunication Union (2021), where institutional framework is identified as a key driver of ICT adoption and the 4IR. Moreover, the crucial importance of government effectiveness in the creation and implementation of policies for the ICT adoption in certain economies and their successful transition toward the 4IR is also emphasized.

Economic growth is represented by d_GDPgro, measuring annual GDP growth in percentages. FDI is represented by d_FDI, indicating the percentage of inward FDI global flows in a certain country. Globalization is represented by d_KOF, which refers to the KOF Globalization Index, measuring the level of globalization in a certain country and encompassing the degree of political, economic (trade and financial) and social (cultural, interpersonal and information) globalization. The values of the KOF indicator range from 0 (minimum) and 100 (maximum). These three variables share a common rationale for inclusion: as mentioned previously, the correlation between and the impact of these variables on ICT and the 4IR is a subject of scientific debate, as noted by Shirazi et al. (2010). Another very important reason is a lack of relevant literature related to the correlation among and the impact of these three indicators on ICT adoption and the 4IR, as confirmed by Veeramacheneni et al. (2007) and Zahid et al. (2018). In addition, FDI is incorporated because studies such as Glass and Saggi (2008) and Gheribi (2018) identify it as a crucial factor for technology, knowledge and information transfer, which are also the core elements of the 4IR and ICT adoption. GDP growth is used as a proxy for economic growth because the World Bank (2024b) and Callen (2024) identify it as the most widely used indicator of economic growth and prosperity. FDI as a percentage of global flows is used because UNCTAD (2024) identifies it as one of the most used indicators of FDI in certain economy. The KOF Globalization Index is used as a proxy for globalization since it represents the most comprehensive indicator of globalization encompassing its various aspects, such as political, economic and social globalization, as confirmed by relevant literature like Hussain (2022).

Table 2 shows a correlation matrix used to test multicollinearity.

Table 2: Correlation matrix

d_ICT	d_GDPgro	d_inst	d_goveffest	d_KOF	d_FDI	
1.0000	0.0553	-0.1475	0.0686	0.1798	0.1469	d_ICT
	1.0000	-0.0860	0.0837	0.0207	0.3956	d_GDPgro
		1.0000	0.0212	0.0761	-0.0372	d_inst
			1.0000	-0.0321	0.0320	d_goveffest
				1.0000	0.0838	d_KOF
					1.0000	d_FDI

Source: Author's calculations

The results show that there is no multicollinearity, as all coefficients are below the critical threshold of 0.5. Certain unexpected signs appear, such as negative correlations between institutional quality and GDP growth, between globalization and government effectiveness, or between FDI and institutional framework, but their magnitudes are small and close to zero.

The first differences of all variables were used to avoid the problem of non-stationarity, since non-stationary variables can provide misleading results and create the problem of potential spurious correlation. The KPSS test (Kwiatkowski–Phillips–Schmidt–Schin) was used, as it is one of the tests with the highest usage rates, according to Baumohl and Lyosa (2009). Since the period in the model is relatively short (2012-2019), the KPSS test is considered the most suitable because, according to Lee and Schmidt (1996), its explanatory power and accuracy are higher than in other tests, while Arltova and Fedorova (2016) state that it is the most suitable test for shorter time periods and enables higher reliability than other tests. The results of the unit root test can be found in Table 3.

Table 3: Unit root test

Variable	P-value - constant	P-value – with constant and trend
d_ICT	0.5994	0.9785
d_FDI	0.9456	0.9359
d_inst	0.1091	0.1248
d_GDPgro	0.5676	0.6611
d_KOF	0.9252	0.9507
d_gov	0.5123	0.6361

Source: Author's calculations

The null-hypothesis of the KPSS test is that the data is stationary. In first differences, all variables are higher than the critical threshold |p| > 0.05, confirming the null hypothesis and the absence of unit roots.

Based on the theoretical framework and previous tests, the following econometric model was constructed:

$$d\_ICT_{it} = \beta_0 + \beta_1 d_{ICT(-1)_{i(t-1)}} - \beta_2 d_{FDI_{it}} - \beta_3 d\_inst_{it} + \beta_4 d\_GDPgro_{it} +$$

$$+ \beta_5 d\_KOF_{it} + \beta_6 d\_gov_{it} + \sum_{t=2014}^{2018} year_t + u_{it} + v_{it}$$

The model contains one dependent variable and five independent variables whose associations with the dependent variable are tested. The next section presents the results of the model, along with robustness check and diagnostic tests assessing model consistency.

5. Results and discussion

This section is divided into two subsections. The first subsection presents the results of the empirical analysis examining the determinants of ICT development and the transition toward the 4IR in the EU. The second subsection is a discussion of the findings.

5.1. Results

This subsection presents and interprets the results of the dynamic panel GMM estimator, used to test the hypotheses and determine the association between FDI, GDP growth, institutional framework and globalization with ICT adoption and the 4IR. The first differences of all variables were taken to avoid the non-stationarity issue.

The results of the model can be found in Table 4, while Table 5 presents model diagnostics.

Table 4: Results of the model

	Coefficient	Std. Error	z	p-value	
d_ICT (-1)	0.0960535	0.00601544	15.97	<0.0001	***
d_GDPgro	0.208947	0.0601555	3.473	0.0005	***
d_inst	0.334130	0.131318	2.544	0.0109	**
d_goveffest	8.57843	2.83578	3.025	0.0025	***
d_KOF	0.857557	0.0557990	15.37	<0.0001	***
d_FDI	0.375674	0.152003	2.471	0.0135	**

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 5: Model diagnostics

Number of instruments	25
Number of observations	162
Test for AR(1) errors: z	-3.78642 [0.0002]
Test for AR(2) errors: z	0.484416 [0.6281]
Sargan over-identification test: Chi-square(19)	22.4839 [0.2608]
Wald (joint) test: Chi-square(6)	2609.59 [0.0000]
Sum squared resid	6875.426
S.E. of regression	6.638768

Source: Author's calculations

The findings confirm that all independent variables are statistically significant. The lagged dependent variable is significant at the level $p<0.01$, while only the d_inst variable, which is one of the proxies for the institutional framework, is significant at the level $p<0.05$. The number of observations usually follows the formula N x (T-2). N represents the number of units – that is, 27 countries – and T the number of time periods – that is, 8 years. Thus, 27 x (8-2) = 162 observations. The dataset originally contained 216 observations but 54 (27 units x 2 years) were lost due to first differences and lagged dependent variable, resulting in 162 usable observations.

The results confirm a positive and statistically significant association of the lagged dependent variable d_ICT(-1). A one-point increase in the ICT infrastructure score in the previous year is associated with a 0.0960535-point increase in the following year. The d_gov variable, one of the proxies for institutional framework that measures government effectiveness, reaches the highest coefficient value related to the association with ICT adoption and the 4IR. A one-point increase in the government effectiveness score is associated with an 8.57843-point increase in the ICT infrastructure score. As for the second institutional variable, d_inst, a one-point increase of its value is associated with a 0.33413-point increase in the ICT infrastructure score. For both indicators, the association is positive and statistically significant. The d_FDI variable, which is taken as a proxy for investment activity, is positively and statistically significant associated with ICT adoption and the 4IR. A 1% increase in the share of global inward FDI flows in one country corresponds to a 0.375674-point increase in the ICT infrastructure score. Economic growth is also positively and significantly associated with ICT adoption and 4IR. A 1% increase in the annual GDP growth is associated with a 0.208947-point increase in the ICT infrastructure score. These findings suggest that after government effectiveness, globalization has the second-highest coefficient value related to the association with ICT adoption and the 4IR. A one-point increase in KOF Globalization Index score is associated with a 0.857557-point increase in the ICT infrastructure score.

Besides the fact that all independent variables and a lagged dependent variable have a positive and statistically significant association with the dependent variable, all variables display expected signs, and the results of the model are in accordance with economic theory.

Model diagnostics confirm the precision and the accuracy of the model. The Arellano-Bond test confirms that there is first-order autocorrelation, but there is no second-order autocorrelation, since the result of the AR2 test is 0.6281, and this value is higher than the critical threshold of 0.5. The results of the Arellano-Bond test reject the hypothesis that there is second-order autocorrelation. The result of the Sargan test is 0.2608, which is higher than the critical threshold of 0.05, confirming the validity of the instruments and the stability of the model. The results of the Wald test confirm sufficient explanatory power of the variables in the model. Together with the KPSS test, these diagnostics confirm that the model is suitable for this research and provides accurate results.

Standard errors (SE) are very small (<2) for all variables, except for government effectiveness, where SE is 2.83578, which is significantly lower than the coefficient value. Furthermore, the p-value for this variable is significant in 99%, while for other variables significance is 95% and 99%. The absence of second-order autocorrelation and the validity of instruments confirmed by the Sargan test further support model robustness. A robust covariance estimator was used and therefore, standard error values are acceptable.

To check the robustness of the results, as shown in Appendix 1, besides testing multi-collinearity, several additional models were created, and in each one, one independent variable from the original model was excluded. Across all models, the effects of the remaining independent variables on the dependent variable remained positive and significant. Coefficient magnitudes changed slightly, but there were no big differences. Government effectiveness consistently showed the highest coefficient value, ranging from 5.31 to 9.49 (compared to 8.57 in the main model). Significance levels varied between 1% and 5%, except for FDI (when institutional variables were omitted) and institutional quality (when GDP growth was omitted), where significance was 10%. A second robustness check, which can be found in Appendix 2, related to adding one by one variable in the model based on theoretical findings. The aim of this was to test the sensitivity of coefficients. Government effectiveness was the first tested variable, since it is represented as a crucial determinant of ICT development, followed by institutional quality, globalization and FDI. The d_inst variable was insignificant in the model where two institutional variables and globalization were included and showed 10% significance when GDP growth was excluded. In all other cases, independent variables were significant at the level of 1%. Coefficients for all variables remained positive, with a higher sensitivity observed for government effectiveness, which was expected given its strong association with ICT. For all other variables, coefficients variation remained below 1.

In models where only one variable was excluded, no second-order autocorrelation was detected, since AR2 was higher than the critical threshold of 0.5, except for the model excluding globalization, where the AR2 was 0.4731. The Sargan test results were higher than the critical threshold of 0.05, confirming instrument validity and model stability. The results of the Wald test confirmed sufficient explanatory power of the variables in the model.

5.2. Discussion

The most important findings in this research concern the identification of the determinants of ICT adoption and the 4IR, a topic which remains understudied according to relevant literature, such as Walsham (2017) and Muscio and Ciffolilli (2019). This study contributes to the scientific discussion by providing new insights into the topic consistent with the literature reviewed in the introduction and literature review sections. The results confirm a positive and significant impact of GDP growth, FDI, institutional framework and globalization level on ICT adoption and the 4IR within the EU. These findings align with existing research. The International Telecommunication Union (2021) and King et al. (1994) emphasize institutional framework, particularly government effectiveness, as a key precondition for ICT adoption and the 4IR, a point further reinforced by Baccianti et al. (2022) for the EU context. Regarding other determinants, such as globalization, economic growth and FDI, the literature remains limited, and their impact on ICT and the 4IR is still a subject of scientific discussion, as noted by Veeramacheneni et al. (2007). Nevertheless, the findings of this research are in accordance with the relevant literature, such as Pradhan et al. (2019), Banerjee et al. (2019), Gholami et al. (2006), Škare and Riberio Soriano (2021) and Camilla et al. (2013).

This research contributes to economic theory by addressing the research gap concerning the impact of economic growth, FDI and globalization on ICT adoption and the 4IR – an area recognized as scientifically important, which is confirmed by Zahid et al. (2018), Broz et al. (2020) Veeramacheneni et al. (2007). A more detailed overview of the scientific contributions is provided in the conclusion.

The results of this research provide a foundation for practical contributions, particularly in the development of policy guidelines. For the EU, the development of a high-quality institutional framework adjusted to the digital age is essential, enabling government effectiveness in the creation and implementation of policies related to ICT adoption and the 4IR. EU policy makers should consider redirecting public priorities on ICT, and, crucially, ensuring the consistent implementation of policies that support ICT adoption and the 4IR to encourage competitiveness on country and company level. Institutions have to ensure the rule of law and create a regulatory framework that will foster market competition. Governments should create public policies that support ICT adoption and the 4IR, thereby enabling reindustrialization. Since institutional quality also comprises elements of business regulations, EU institutions and national authorities must create a macroeconomic environment that encourages private-sector initiatives in the transition toward the 4IR and ICT development. As the 4IR is closely tied to reindustrialization and the manufacturing sector (predominantly privately owned), EU regulations should aim to reduce business barriers and enhance market competition. Businesses should become active stakeholders in shaping an institutional framework adjusted to the needs and requests of the 4IR. Through professional associations, such as Economic Chambers, they can engage in public discussions on institutional reforms and contribute to improving government effectiveness. Public policy measures should therefore strengthen not only public institutions, but also companies in the EU market and the overall investment environment. Since firms are most familiar with the practical effects of regulations, they should communicate challenges to policy makers, who can then make informed decisions.

Further economic and political liberalization and globalization should remain priorities for EU policy makers. Although globalization currently faces certain challenges, Boretos (2009) explains that global relations have historically fluctuated due to wars, crises, pandemics and protectionism, yet the process has never ended. Papanikos (2024; 2025) and the KOF Swiss Economic Institute (2024) confirm, based on historical trajectories and the first presidency of Donald Trump, that despite periods of deglobalization, globalization will continue due to the substantial benefits it provides. They explain that globalization trends have changed over time due to an increasing or decreasing level of globalization. New geopolitical relations may lead to protectionist measures, such as tariffs, being imposed on the EU by the US government. Such developments could motivate the EU to foster cooperation with different trade partners worldwide and enhance bilateral cooperation in all fields. It is important that the EU continues expanding its network of free trade agreements (FTAs), such as that with Mercosur started in December 2024, which created a market of 800 million people (European Comission, 2024). EU is the world's largest single market and an attractive investment and trade destination. Despite potential protectionist measures imposed by the US administration, the EU should seek to redefine its political and economic relations with the US, since they are major trading partners and allies, and especially because the USA has reached its peak of globalization during the first presidency of Donald Trump. As Papanikos (2025) argues, globalization is a natural and ongoing process and it is impossible to end it. Although the USA and the EU are major trade partners, they have not yet signed an FTA. Strengthening globalization and redefining trade relations with the US, potentially through an FTA, could reduce tariffs, eliminate trade barriers, and increase business dynamism and competition within the EU market. Expanding and updating FTAs would lead to faster integration into global trade and investment flows, increasing FDI inflows into the EU. FDI represents one of the most powerful channels for transferring and diffusing technology, knowledge, and information, contributing to further ICT adoption and the 4IR. Such an economic environment would stimulate economic activity, foster GDP growth and further advance ICT adoption and the transition toward the 4IR. Since companies and businesses are expected to become active stakeholders in adjusting the institutional framework, they have to be ready to adapt to challenges and solutions in the new global environment. In addition to the FTA with Mercosur, the new FTA in India, described by the European Comission (2026) as EU's largest trade agreement, creates a market of two billion consumers, with tariffs on 96.6% of EU products removed or decreased. Companies should therefore adjust their business strategies to the evolving global market to fully benefit from these opportunities and enhance their competitiveness.

6. Conclusion

The aim of this research was to identify the determinants of ICT adoption and the 4IR in the EU. The main motivation was to contribute to scientific discussion and economic theory by examining relatively new and understudied topics – ICT and the 4IR – and providing evidence-based policy guidelines. A comprehensive literature review established the theoretical foundation for selecting the independent variables and confirmed the research gap outlined in the problem statement. The tested hypotheses were supported by the econometric model, whose results represent the central findings of this study. These results highlight the importance of FDI, economic growth, institutional framework and globalization for ICT adoption and the 4IR, with institutional framework representing a crucial determinant with the biggest and the most significant impact.

The results of the econometric model, combined with the comprehensive literature review, form the basis for both the theoretical and practical contributions of this research. The most important theoretical contribution of this paper is the identification of the drivers of ICT adoption and the 4IR, thereby expanding existing knowledge and offering new insights into these topics. The study also contributes to the scientific discussion on the correlation among FDI, economic growth and globalization with ICT adoption and the 4IR. An additional contribution stems from the observed sample, the EU, which has positioned the 4IR as a crucial development strategy for increasing competitiveness level, while setting ICT adoption as a key strategic priority. This study fills the gap in economic science by offering new insights into relevant economic, societal and practical challenges associated with ICT adoption and the 4IR, as well as their links to economic growth, FDI and globalization. The practical contributions, particularly the policy guidelines, are discussed in detail in the discussion section.

Despite its contributions, this research faces certain limitations. One major limitation is the scarcity of comprehensive studies on ICT and the 4IR, as well as their correlation with determinants such as FDI, GDP growth, and globalization. This gap served as the main motivation for the study, as its findings provide new knowledge related to economic science and make this research relevant. Another limitation concerns the indicators. Although multiple indicators of ICT adoption and the 4IR exist, the study uses the ICT infrastructure from the World Intellectual Property Organization (2024) Global Innovation Index Database because it is comprehensive and because it encompasses different aspects of ICT. While other drivers and determinants of ICT adoption exist, the use of system GMM helps mitigate omitted-variable bias and ensures the robustness and validity of the results through diagnostic testing. A further limitation is the exclusion of the UK due to Brexit, as the policy guidelines are focused on the period after Brexit. Although Brexit was voted on during the observed period (in 2016), it took effect in 2020, while the final year in the model is 2019.

Further research could include other variables like human capital quality, investments in R&D and education, quality of education system, index of economic freedom, trade openness, environmental indicators, and population, and examine their correlations with ICT adoption and the 4IR. Another area for further research is using a sample of different groups of countries, as the 4IR is a global challenge, and comparing the EU with its main competitors. Further research could also explore the broader social and economic impacts of ICT and the 4IR.

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Determinante razvoja informacijsko-komunikacijske tehnologije i tranzicije prema četvrtoj industrijskoj revoluciji u Europskoj uniji

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Sažetak

Informacijsko-komunikacijska tehnologija (IKT) mijenja svijet i rapidno preoblikuje društvene i ekonomske paradigme. Ona je ključni pokretač četvrte industrijske revolucije (4IR) koja predstavlja novu paradigmu u digitalnoj transformaciji, industriji i tehnološkom razvoju. Unutar Europske unije (EU), 4IR postala je strateški prioritet usmjeren na smanjenje razvojnog jaz u odnosu na njezine najvažnije konkurente, kao što su Sjedinjene Američke Države i Kina. Ovo istraživanje nastoji povećati znanja i produbiti razumijevanje IKT-a i 4IR-a, kao i njihovih pokretača. Glavni je cilj ovog rada utvrditi determinante razvoja IKT-a i 4IR-a u EU u razdoblju između 2012. i 2019. godine. Za postizanje tog cilja korišten je dinamički panel procjena generalizirane metode momenata (eng. GMM) u dva koraka. Ključni rezultati pokazuju da su izravna strana ulaganja, institucionalni okvir, ekonomski rast i globalizacija pozitivno i statistički značajno povezani s razvojem IKT-a i tranzicijom prema 4IR-u. Budući da IKT i 4IR predstavljaju ključne pokretače i strateške prioritete razvoja na EU i globalnoj razini, nositelji javnih politika u EU trebali bi se usmjeriti na stvaranje makroekonomskog i političkog okruženja koje će poticati digitalnu transformaciju i brže širenje IKT tehnologije.

Ključne riječi: *informacijsko-komunikacijska tehnologija, četvrta industrijska revolucija, Europska unija, generalizirana metoda momenata*

JEL klasifikacija: *O30, O10, F63, L52*

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Appendix

Appendix 1: Robustness checks

Table 6: Results of original model

	Coefficient	Std. Error	z	p-value	
d_ICT (-1)	0.0960535	0.00601544	15.97	<0.0001	***
d_GDPgro	0.208947	0.0601555	3.473	0.0005	***
d_inst	0.334130	0.131318	2.544	0.0109	**
d_goveffest	8.57843	2.83578	3.025	0.0025	***
d_KOF	0.857557	0.0557990	15.37	<0.0001	***
d_FDI	0.375674	0.152003	2.471	0.0135	**

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 7: Model diagnostic

Number of instruments	25
Number of observations	162
Test for AR(1) errors: z	-3.78642 [0.0002]
Test for AR(2) errors: z	0.484416 [0.6281]
Sargan over-identification test: Chi-square(19)	22.4839 [0.2608]
Wald (joint) test: Chi-square(6)	2609.59 [0.0000]
Sum squared resid	6875.426
S.E. of regression	6.638768

Source: Author's calculations

Table 8: Robustness check 1: without institutional variables

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0617702	0.0164452	3.756	0.0002	***
d_GDPgro	0.244925	0.0465294	5.264	<0.0001	***
d_KOFGlobaliza~	0.779534	0.0797528	9.774	<0.0001	***
d_FDIgloflow	0.245441	0.131553	1.866	0.0621	*

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors

Source: Author's calculations

Table 9: Robustness check 1 – Model diagnostic

Number of instruments	23
Number of observations	162
Test for AR(1) errors: z	-3.92765 [0.0001]
Test for AR(2) errors: z	0.274982 [0.7833]
Sargan over-identification test: Chi-square(19)	23.0095 [0.2369]
Wald (joint) test: Chi-square(6)	493.643 [0.0000]
Sum squared resid	6863.455
S.E. of regression	6.590871

Source: Author's calculations

Table 10: Robustness check 2 – Excluded variable: institutions

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0882318	0.00991590	8.898	<0.0001	***
d_GDPgro	0.206787	0.0516327	4.005	<0.0001	***
d_KOFGlobaliza~	0.876467	0.0726448	12.07	<0.0001	***
d_FDIgloflow	0.288463	0.135339	2.131	0.0331	**
d_goveffest	8.52675	2.55014	3.344	0.0008	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 11: Robustness check 2 – Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.84452 [0.0001]
Test for AR(2) errors: z	0.574333 [0.5657]
Sargan over-identification test: Chi-square(19)	23.8759 [0.2010]
Wald (joint) test: Chi-square(6)	671.781 [0.0000]
Sum squared resid	6849.211
S.E. of regression	6.604964

Source: Author's calculations

Table 12: Robustness check 3: Excluded variable: government effectiveness

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0681707	0.0130563	5.221	<0.0001	***
d_GDPgro	0.229574	0.0545010	4.212	<0.0001	***
d_KOFGlobaliza~	0.746567	0.0632193	11.81	<0.0001	***
d_FDIgloflow	0.342602	0.134871	2.540	0.0111	**
d_inst	0.454053	0.145043	3.130	0.0017	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 13: Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.81871 [0.0001]
Test for AR(2) errors: z	0.114319 [0.9090]
Sargan over-identification test: Chi-square(19)	20.4415 [0.3685]
Wald (joint) test: Chi-square(6)	1075.73 [0.0000]
Sum squared resid	6935.696
S.E. of regression	6.646534

Source: Author's calculations

Table 14: Robustness check 4: Excluded globalization variable

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0454805	0.00668416	6.804	<0.0001	***
d_GDPgro	0.195120	0.0577587	3.378	0.0007	***
d_FDIgloflow	0.389039	0.122779	3.169	0.0015	***
d_inst	0.481386	0.151266	3.182	0.0015	***
d_goveffest	5.31556	0.975822	5.447	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 15: Robustness check 4: Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.80383 [0.0001]
Test for AR(2) errors: z	0.717461 [0.4731]
Sargan over-identification test: Chi-square(19)	21.9402 [0.2872]
Wald (joint) test: Chi-square(6)	215.315 [0.0000]
Sum squared resid	7325.886
S.E. of regression	6.830937

Source: Author's calculations

Table 16: Robustness check 5: Excluded FDI variable

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0928388	0.00859438	10.80	<0.0001	***
d_GDPgro	0.325509	0.0304441	10.69	<0.0001	***
d_inst	0.349498	0.149786	2.333	0.0196	***
d_goveffest	8.56867	3.03534	2.823	0.0048	***
d_KOFGlobaliza~	0.885442	0.0499963	17.71	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 17: Robustness check 5 - Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.81347 [0.0001]
Test for AR(2) errors: z	0.199614 [0.8418]
Sargan over-identification test: Chi-square(19)	22.0112 [0.2837]
Wald (joint) test: Chi-square(6)	5671.27 [0.0000]
Sum squared resid	6911.872
S.E. of regression	6.635108

Source: Author's calculations

Table 18: Robustness check 6: Excluded GDP growth variable

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0835745	0.00729621	11.45	<0.0001	***
d_inst	0.312665	0.181635	1.721	0.0852	*
d_goveffest	9.49894	2.45144	3.875	0.0001	***
d_KOFGlobaliza~	0.836041	0.0523850	15.96	<0.0001	***
d_FDIgloflow	0.524715	0.111396	4.710	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 19: Robustness check 6 - Model diagnostics

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.852 [0.0001]
Test for AR(2) errors: z	0.767744 [0.4426]
Sargan over-identification test: Chi-square(19)	23.3042 [0.2242]
Wald (joint) test: Chi-square(6)	1785.7 [0.0000]
Sum squared resid	6996.155
S.E. of regression	6.675440

Source: Author's calculations

Appendix 2: Building the Model

Table 20: ICT – government effectiveness

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.00939026	0.00622203	1.509	0.1312	
d_goveffest	5.10440	1.81816	2.807	0.0050	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 21: Model diagnostics ICT – government effectiveness

Number of instruments	21
Number of observations	162
Test for AR(1) errors: z	-4.00802 [0.0001]
Test for AR(2) errors: z	1.18982 [0.2341]
Sargan over-identification test: Chi-square(19)	23.7916 [0.2043]
Wald (joint) test: Chi-square(6)	7.95532 [0.0187]
Sum squared resid	7530.141
S.E. of regression	6.860275

Source: Author's calculations

Table 22: ICT – institutional variables

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0218745	0.0111433	1.963	0.0496	**
d_goveffest	6.13868	1.96222	3.128	0.0018	***
d_inst	0.377055	0.114696	3.287	0.0010	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 23: Model diagnostics ICT – institutional variables

Number of instruments	22
Number of observations	162
Test for AR(1) errors: z	-3.96219 [0.0001]
Test for AR(2) errors: z	1.0836 [0.2785]
Sargan over-identification test: Chi-square(19)	22.0565 [0.2815]
Wald (joint) test: Chi-square(6)	19.4696 [0.0002]
Sum squared resid	7575.251
S.E. of regression	6.902397

Source: Author's calculations

Table 24: ICT – institutional variables and globalization

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0625349	0.0117203	5.336	<0.0001	***
d_goveffest	9.18431	2.65545	3.459	0.0005	***
d_inst	0.175773	0.178549	0.9844	0.3249	
d_KOFGlobaliza~	0.900114	0.0409300	21.99	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 25: Model diagnostics ICT – institutional variables and globalization

Number of instruments	23
Number of observations	162
Test for AR(1) errors: z	-3.91629 [0.0001]
Test for AR(2) errors: z	0.708426 [0.4787]
Sargan over-identification test: Chi-square(19)	23.8207 [0.2031]
Wald (joint) test: Chi-square(6)	2271.55 [0.0000]
Sum squared resid	7105.092
S.E. of regression	6.705888

Source: Author's calculations

Table 26: ICT – institutional variables, globalization and FDI

	Coefficient	Std. Error	z	p-value	
d_ICTinfr(-1)	0.0835745	0.00729621	11.45	<0.0001	***
d_goveffest	9.49894	2.45144	3.875	0.0001	***
d_inst	0.312665	0.181635	1.721	0.0852	*
d_KOFGlobaliza~	0.836041	0.0523850	15.96	<0.0001	***
d_FDIgloflow	0.524715	0.111396	4.710	<0.0001	***

Note: The P-values in brackets and the marking *** indicate the significance level up to 1%. The P-values in brackets and the label ** indicate the significance level up to 5%. P-values in brackets and labels * indicate the significance level up to 10%. The P-values were determined by calculating the two-step dynamic procedure; 27 cross-sectional units; Including equations in levels; H-matrix as per Ox/DPD; Asymptotic standard errors.

Source: Author's calculations

Table 27: Diagnostic tests ICT – institutional variables, globalization and FDI

Number of instruments	24
Number of observations	162
Test for AR(1) errors: z	-3.852 [0.0001]
Test for AR(2) errors: z	0.767744 [0.4426]
Sargan over-identification test: Chi-square(19)	23.3042 [0.2242]
Wald (joint) test: Chi-square(6)	1785.7 [0.0000]
Sum squared resid	6996.155
S.E. of regression	6.675440

Source: Author's calculations

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Tourism, Urban Growth and the Ecological Footprint: Empirical Insights from the European Union*

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Abstract

Tourism, urban growth, and ecological sustainability are becoming increasingly intertwined in the European Union, where rapid urban expansion and economic activity intensify ecological pressures. Understanding how tourism interacts with these dynamics has become central to the sustainable tourism debate, as policymakers and stakeholders seek to balance economic development with environmental protection. This study examines the short- and long-run effects of tourism activity, urbanization, economic growth, and renewable energy consumption on the ecological footprint across 14 EU countries from 1995 to 2024. Employing the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) model, which accounts for cross-sectional dependence and slope heterogeneity, the analysis confirms a long-run cointegrating relationship among the variables. Findings indicate that economic growth and urbanization

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significantly increase ecological footprint, whereas international tourism exerts a mitigating effect on environmental pressures. Renewable energy contributes to ecological improvement in the long run, though its short-run impact is limited. These results underscore the need for integrated policy frameworks that combine sustainable tourism development, urban planning, and renewable energy strategies within the European Union. The study underscores the importance of coordinated action among urban planners, energy policymakers, and tourism stakeholders to foster economic growth while ensuring environmental sustainability for future generations.

Keywords: *sustainable tourism development, urbanization, ecological footprint assessment, environmental sustainability, renewable energy adoption, economic growth dynamics, European Union*

JEL classification: *L83, Q56, R11*

1. Introduction

Sustainable tourism research has increasingly emphasized that *sustainability* is not a single environmental indicator but an integrated, contested, and governance-laden project spanning environmental limits, socio-economic distribution, and institutional choices—an orientation long embedded in debates (Bramwell et al., 2017). At the core of this debate lies a fundamental tension: how to reconcile mobility-driven economic growth—of which tourism is a central component—with biophysical limits and climate-neutrality ambitions. In parallel, the spatial locus of sustainability has become unmistakably urban: more than half of the world's population now lives in cities, and urban systems are simultaneously engines of economic output and major sources of greenhouse gas emissions (United Nations Statistics Division, 2022; Ritchie et al., 2024). Previous research has documented an increase in the global tourism carbon footprint from approximately 3.9 $GtCO_2e$ in 2009 to 4.5 $GtCO_2e$ in 2013, representing around 8% of total anthropogenic greenhouse gas emissions (Lenzen et al., 2018). Updated estimates based on extended multiregional input–output modelling indicate that the global tourism carbon footprint reached approximately 5.2 $GtCO_2e$ in 2019, accounting for around 8.8% of total global emissions, with the sector's average annual growth rate exceeding that of global emissions over the same period (Sun et al., 2024). These findings highlight a pronounced scale effect, whereby growth in mobility and tourism consumption outpaces technological improvements and relative gains in energy efficiency.

Following the pandemic-related contraction, more recent evidence indicates a partial reduction in tourism's relative emission share, with the sector contributing between 6.5% and 7.3% of global greenhouse gas emissions in 2023–2024 (World Travel and Tourism Council, 2024, 2025). However, a lower relative share does not necessarily imply absolute decoupling between tourism growth and environmental pressure. Rather, it may reflect temporary disruptions in mobility patterns alongside composition and technology effects. This raises a critical question: do tourism dynamics in highly developed and regulation-intensive regions demonstrate structural alignment with climate neutrality objectives, or does the sector remain constrained by inherent biophysical limits? For the European Union (EU), these dynamics are especially policy-salient. The region has positioned itself as a climate-policy frontrunner while simultaneously promoting tourism competitiveness and resilience through initiatives such as the European Green Deal and the Tourism Transition Pathway (European Commission, 2022). Consequently, the EU represents not merely a geographic sample, but a multi-level governance laboratory for climate–tourism integration, in which climate neutrality, urban development, and tourism policy are institutionally intertwined.

Despite a fast-growing literature on tourism–environment linkages, two limitations remain consequential for sustainable tourism policy in advanced, interconnected regions. First, evidence is often built on single-emission indicators or territorial inventories, which may understate consumption-driven pressures and global supply-chain effects, By contrast, the ecological footprint operationalizes environmental pressure as demand on biologically productive area required to provide consumed resources and absorb wastes (including carbon demand), thus aligning well with sustainability questions framed around lifestyles, mobility, and urban consumption systems (Global Footprint Network, n.d.). Although the ecological footprint is not without methodological critique, its consumption-based logic offers a normatively consistent metric for evaluating tourism within broader urban metabolism and lifestyle-oriented sustainability debates. Second, even within Europe—where tourism is economically significant and climate and carbon risks are widely recognized—important gaps persist in coherent national and sub-sector emissions evidence and in research systematically connecting climate-policy transitions to tourism dynamics. These gaps matter because the sign of tourism's environmental association remains theoretically ambiguous. From a political-economy perspective, tourism may generate scale effects that amplify ecological pressure through mobility and consumption expansion; yet in high-income, regulation-intensive settings it may also produce composition and technology effects linked to cleaner energy systems, environmental innovation, and sustainability governance. The core empirical problem, therefore, is not whether tourism *matters*, but under what structural and policy conditions tourism intensity coincides with higher or lower consumption-based environmental pressure once urbanization and economic growth dynamics are jointly considered. Against this backdrop, examining tourism–environment dynamics within advanced European economies provides an opportunity to assess whether high-income, regulation-intensive contexts facilitate relative or absolute decoupling, or whether tourism growth continues to generate net ecological pressure. By integrating ecological footprint indicators with tourism and macroeconomic variables, this study seeks to provide new empirical evidence on sustainable tourism transitions in regulation-intensive European contexts.

To address this problem, the study investigates the following research questions:

> RQ1: *What are the long-run and short-run effects of tourism activity and urbanization on ecological footprint in the EU context?*
>
> RQ2: *To what extent can renewable energy transitions compensate for tourism- and urbanization-driven consumption pressures?*
>
> RQ3: *After accounting for cross-country interdependence, do tourism dynamics appear footprint-amplifying or footprint-mitigating in the long run?*

Conceptually, the empirical specification is consistent with an extended consumption-pressure framework in which environmental impact reflects the combined influence of affluence (economic output), structural-demographic change (urbanization), technology and energy system characteristics (renewables), and sectoral demand shocks (tourism). This framework allows for the possibility that tourism operates simultaneously as a driver of environmental scale effects and as a vector of structural transformation within advanced urban economies. Methodologically, the paper employs a cross-sectionally augmented ARDL approach suited to macro-panels with cross-sectional dependence and dynamic adjustment, enabling simultaneous estimation of long-run relationships and short-run error-correction dynamics (Chudik & Pesaran, 2015). This strategy is complemented by second-generation panel procedures that explicitly recognize cross-sectional dependence in non-stationary settings, strengthening inference in integrated regions where common shocks and spillovers are plausible (Pesaran, 2007; Westerlund, 2007).

The paper makes four original contributions to sustainable tourism scholarship and EU-relevant policy debates. First, it reframes tourism–environment relations around ecological footprint, a consumption-oriented pressure metric that captures broader ecological demand than CO_2-only indicators and is therefore more closely aligned with sustainability's integrated remit (Global Footprint Network, n.d.). Second, it provides updated longitudinal evidence for an EU country panel (1995–2024), a period spanning deepening urbanization, acceleration of energy transition policies, and intensified sustainability governance under EU climate-neutrality commitments (European Commission, 2022). In doing so, it offers rare empirical insight into whether tourism intensity in advanced, highly urbanized economies is structurally compatible with ecological sustainability objectives. Third, by using cross-sectionally augmented dynamic panel techniques, it offers an empirically robust test of whether tourism is footprint-amplifying or footprint-mitigating once urban growth, income dynamics, and renewable energy are jointly modelled under cross-country interdependence (Chudik & Pesaran, 2015). Fourth, the findings speak directly to a central sustainable tourism governance dilemma emphasized in climate-transition scholarship: aligning tourism development trajectories with climate-neutrality ambitions requires evidence on where economic and urban benefits coincide with measurable reductions (or increases) in environmental pressure, and which policy levers—especially renewable energy—are empirically associated with footprint mitigation (Scott, 2024; Peeters & Papp, 2024). By situating tourism within broader debates on green growth, urban transition, and multi-level climate governance, the study contributes to ongoing discussions about the structural conditions under which tourism can coexist with ecological stabilization in advanced economies.

After the introductory section, the paper provides a review of the relevant empirical literature examining the relationship between tourism, economic growth, urbanization, and emissions. It then outlines the research methodology and presents the empirical results, followed by a detailed discussion of the findings. The concluding section offers policy recommendations and suggests directions for future research.

2. Literature review

Recent scholarship in sustainable tourism has increasingly adopted the ecological footprint as a comprehensive indicator capturing the cumulative environmental pressures associated with tourism development. While tourism expansion supports economic growth, empirical evidence links tourism growth with increased ecological pressures—including resource use, land transformation, and greenhouse gas emissions—in multi-country panel studies (Paramati et al., 2017b; Khan & Hou, 2021). At the EU level, recent panel analyses show that tourism development is significantly associated with higher carbon emissions, indicating that urbanized tourism destinations experience amplified environmental pressures as tourism and related economic activity expand (Nwaeze et al., 2023; Marić Stanković et al., 2024). In urban contexts, these pressures are often intensified through dense infrastructure, higher transport demand, and spatial concentration of tourism activities, making cities critical nodes in the sustainability debate.

A growing body of literature conceptualizes tourism as an integral component of urban systems rather than an isolated sector. Casals Miralles et al. (2023) emphasize that single-indicator approaches underestimate tourism's environmental impact and advocate for integrated assessments combining carbon, water, and ecological footprints. Empirical evidence from Mediterranean and coastal destinations indicates that tourism intensity and spatial concentration substantially increase ecological and carbon footprints, particularly in highly urbanized regions (Gössling et al., 2015). At the EU level, empirical research indicates that tourism growth is associated with higher environmental pressures, as tourism expansion exerts a negative effect on environmental sustainability—including ecological footprints—when analysed across groups of European Union countries, suggesting that tourism and related urban development can intensify environmental degradation under certain conditions (Torres-Díaz et al., 2025, Veljković et al., 2025). Complementing this perspective, empirical research shows that hidden carbon emissions embedded in tourism-related supply chains—such as indirect emissions from accommodation and related sectors—often exceed direct emissions, demonstrating the need for policy reforms targeting *urban tourism systems* to reduce environmental pressures (Zhang & Xia, 2024).

Methodologically, the literature is dominated by panel econometric approaches designed to capture long-run relationships and cross-sectional dependence across countries. Techniques such as FMOLS, DOLS, and CS-ARDL are widely employed to address heterogeneity and unobserved common factors in tourism–environment nexus studies (Paramati et al., 2017b; Shaari et al., 2024; Shi & Smith, 2025). Within this framework, several studies test the Environmental Kuznets Curve (EKC) hypothesis, proposing that environmental pressures initially increase with tourism and urban expansion before stabilizing at higher income levels. Empirically, research on the tourism–environment nexus increasingly relies on panel econometric approaches to capture long-run relationships and cross-sectional dependence across countries. Estimators such as FMOLS and DOLS are widely applied to account for heterogeneity and unobserved common factors in empirical studies, while recent applications of CS-ARDL provide additional robustness in capturing both short- and long-run dynamics. Empirical evidence demonstrates the relevance of these methods in analysing the dual impact of tourism on economic growth and environmental pressures (Paramati et al., 2017a; Shahzad et al., 2017; Khan et al., 2019; Marković et al., 2023). Complementary findings suggest the presence of non-linear relationships consistent with the Environmental Kuznets Curve hypothesis, although tourism-driven urban regions may struggle to reach such turning points without substantial structural and policy interventions. In parallel, studies published in the *Journal of Sustainable Tourism* highlight inter-market variability in tourism-related emissions, showing that CO_2 intensities differ across destinations and emphasizing the need for location-specific, climate-sensitive tourism policies, particularly in highly urbanized and coastal regions (Gössling et al., 2015).

The energy transition has emerged as a key moderating factor in the tourism–environment literature. Empirical studies indicate that greater adoption of renewable energy and environmental technologies is associated with reductions in ecological footprints, even in tourism-dependent economies (Khan et al., 2019; Ali et al., 2021). Sectoral approaches, including input–output analyses, further highlight urban hotspots where tourism-related emissions are concentrated. These findings are consistent with global evidence that tourism-related emissions increased at an average annual rate of approximately 3.5% between 2009 and 2019—nearly twice the growth rate of the overall economy—underscoring the sector's growing environmental significance (Sun et al., 2024).

Beyond environmental and energy dimensions, recent research increasingly incorporates governance, social equity, and institutional frameworks in sustainable tourism studies. Systematic reviews highlight the growing importance of Environmental, Social, and Governance (ESG) frameworks in shaping destination resilience and guiding tourism development, emphasizing that strong institutional quality and governance mechanisms can align tourism growth with sustainability objectives (Abd Rahman et al., 2025; Camilleri, 2025). Empirical studies provide evidence that ESG practices enhance operational efficiency and long-term resilience in tourism and hospitality firms, mitigating the environmental pressures associated with tourism expansion (Lu et al., 2025). Complementing this, bibliometric analyses reveal a growing scholarly focus on ESG dimensions—environmental, social, and governance—within the hospitality and tourism literature, indicating emerging research trends that link governance structures to sustainable tourism outcomes (Legendre et al., 2024). Collectively, these findings underscore the necessity of integrating governance, social equity, and institutional quality into policy-making and strategic planning to achieve more resilient and sustainable urban tourism systems.

The COVID-19 pandemic represents a structural turning point in the tourism–environment discourse. Lockdowns in 2020 led to sharp reductions in tourism-related emissions, yet subsequent recovery in many EU destinations approached or even exceeded pre-pandemic levels (Sigala, 2020; Sun et al., 2024). Sigala (2020) emphasizes that COVID-19 exposed deep vulnerabilities in tourism systems, highlighting the need for resilience and sustainability-oriented strategies. Quantitative analyses show that global tourism carbon emissions grew at an average annual rate of about 3.5% from 2009 to 2019, reaching approximately 5.2 Gt CO_2-equivalent in 2019, underlining the sector's environmental significance and the challenge of aligning recovery with international sustainability targets (Sun et al., 2024). These dynamics demonstrate that integrating destination-specific policies, renewable energy adoption, and resilience planning is critical to ensure sustainable post-pandemic tourism growth.

Despite notable advances, critical gaps remain. Much of the existing literature relies on aggregated national or regional data, which obscures micro-level urban dynamics where environmental pressures manifest through localized pollution, congestion, and biodiversity loss. Recent spatial studies highlight how GIS-based approaches and fine-scale data analytics can reveal tourism pressure at a local level, informing more targeted planning interventions (Salas-Olmedo et al., 2017; Šoltésová et al., 2025; Balletto et al., 2025). Furthermore, the pronounced heterogeneity of EU regions—from densely populated Mediterranean urban zones to more dispersed Alpine settlements—is seldom examined in detail, resulting in overly generalized conclusions. The limited incorporation of emerging tools such as AI-based forecasting and big data from digital tourism platforms further restricts the ability to anticipate future trajectories in line with the EU Green Deal objectives.

Collectively, the literature demonstrates a conceptual and empirical evolution toward a more integrated understanding of sustainable tourism. By linking tourism growth, urbanization, energy transition, and governance frameworks, existing studies establish a solid foundation for advanced empirical analysis (Paramati et al., 2017a; Shaari et al., 2024; Shi & Smith, 2025). Nevertheless, the interaction between tourism-driven urban growth and ecological footprints in the EU—particularly when accounting for cross-sectional dependence and long-run dynamics—remains insufficiently examined. To address these gaps, this study applies the CS-ARDL framework to EU urban tourism contexts, providing robust empirical evidence on both short- and long-run effects of tourism, urbanization, economic activity, and energy consumption on ecological sustainability.

3. Data and methodology

This section presents the methods used, along with the underlying equations and assumptions that form the basis for the subsequent analysis of the results. The sample for this study comprises EU-14 countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain and Sweden). The research applies the operational framework described below, while holding all other factors constant.

$$EF = f(GDP, URB, TOUR, RE) \tag{1}$$

Equation 1 shows that ecological footprint (EF), represented by ecological footprint of consumption, measured in global hectares per person, is influenced by gross domestic product per capita (GDP), urbanisation (URB), international tourist arrivals (TOUR), and renewable energy consumption per capita (RE). The dataset used in this study covers the period from 1995 to 2024 for the EU-14 countries.

$$LEF_{it} = \alpha_0 + \alpha_1 LGDP_{it} + \alpha_2 LURB_{it} + \alpha_3 LTOUR_{it} + \alpha_4 LRE_{it} + \varepsilon_{it} \tag{2}$$

The log-linear model is applied to capture the continuous relationships among the variables in the framework, where α_0, α_1, α_2, α_3, and α_4 represent the respective coefficients. In Equation 2, the error term is denoted by ε_{it}, where i refers to the cross-sectional unit and t refers to the time dimension. A detailed description of all variables is provided in Table 1. Data for all variables are available throughout the entire study period. However, for the tourism variable, missing observations for 2024 in several countries were estimated using interpolation to ensure a balanced panel.

The cross-sectional dependence (CSD) test is applied to identify the appropriate empirical techniques for analysis. The results of this test guide researchers in choosing between first- and second-generation panel data methods. Skipping this diagnostic step may result in biased or unreliable estimates. Cross-sectional dependence typically arises from common shocks and unobserved factors (Hao et al., 2021). Increasing globalization and international economic integration have further intensified interlinkages among countries, making it essential to formally test for CSD to ensure the accuracy and reliability of empirical results. When the time dimension (T) is larger than the cross-sectional dimension (N), the Breusch–Pagan LM test is the preferred approach.

Table 1: Variables description

Abbreviation	Variable	Detail	Sources
LEF	Ecological footprint	Ecological footprint of consumption, measured in global hectares per person	Global Footprint Network (n.d.)
LGDP	Gross domestic product	GDP per capita (constant 2015US$)	World Development Indicators (2025)
LURB	Urbanization	Urban population, % of total population	World Development Indicators (2025)
LTOUR	International tourist arrivals	International tourism, number of arrivals	World Development Indicators (2025) & UN Tourism Data (2025)
LRE	Renewable energy	Renewable energy consumption per capita (kWh)	Our World in Data (2025)

Source: Authors' compilation

Differences in slope parameters across units can also distort panel regression outcomes. Slope heterogeneity refers to variations in coefficients among cross-sectional units (Zeraibi et al., 2021). Considering the structural differences across the countries included in the study, it is necessary to examine whether the slope coefficients vary. Accordingly, the slope heterogeneity test proposed by Pesaran and Yamagata (2008) and refined by Blomquist and Westerlund (2013) was implemented.

The next stage involved assessing the stationarity characteristics of the panel data—specifically, determining whether the variables are stationary in levels or after differencing. For this purpose, the study employed the second-generation cross-sectional augmented Dickey- Fuller (CADF) test developed by Pesaran (2007). This test is commonly used because of its ability to account for cross-sectional dependence and heterogeneity among countries. The CADF is the individual (or single) augmented Dickey–Fuller test described by:

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \beta_i \bar{y}_{t-1} + \sum_{j=0}^{k} \gamma_{i,j} \Delta \bar{y}_{t-1} + \sum_{j=0}^{k} \gamma_{i,j} \Delta y_{t-1} + \varepsilon_{it} \quad (3)$$

where α_i, k and y_t are the constant, the lag specification, and the temporarily defined cross-sectional averages, respectively. Under the null hypothesis, the variables are non-stationary. If the panel unit root test shows that the variables are integrated of the same order, cointegration tests are applied to determine whether one or more long-term equilibrium relationships exist among the examined variables. In this study, both first- and second-generation tests are used. First, Pedroni's (1999, 2004) approach is applied, which proposes a residual-based cointegration test assuming cross-sectionally independent units. Furthermore, the Kao (1999) test was conducted as part of the analysis. Then, Westerlund's (2007) specification is employed, which assumes cross-sectional dependence. Both tests share the null hypothesis of no cointegration. Pedroni's tests rely on a within-dimension approach, which includes four statistics: panel ρ-statistic, panel v-statistic, panel PP-statistic, and panel ADF-statistic. These statistics account for common time factors and heterogeneity among units. A second set of statistics is based on a between-dimension approach and includes three statistics: group ρ, group PP, and group ADF.

Through CS-ARDL, short and long-run coefficients are being measured. Because of its powerful assumptions about CSD, endogeneity, and slope heterogeneity, this method outperforms other cointegration methods. Some issues were perceived when the cross-section correlations in the errors were ignored and to avoid this issue, this study employed panel CS-ARDL. The panel ARDL model is the most widespread heterogeneous panel data estimator, but it fails to address the potential cross-sectional dependence error. Hence, in this study, the Cross-Sectionally Augmented ARDL (CS-ARDL) is applied. Prior studies, Wencong et al. (2023) and Cai and Wei (2023) employed the CS-ARDL robust approach to determine the model's long and short-run coefficients. The panel function of the research, instead of the cross-sectional aspect, instigated the use of the CS-ARDL approach, which is a particularly suitable estimation method in such cases. The CS-ARDL method outperforms traditional empirical models by accounting for slope variability across countries and cross-country dependence, regardless of whether the associated data are nonstationary at the level, I (0), I (1), or mixed order integrated. The equation for the CS-ARDL model can be presented as:

$$y_{i,t} = \alpha_i + \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} x_{i,t-j} + \sum_{j=0}^{K} \varphi'_{ij} \bar{Z}_{i,t-j} + \varepsilon_{it}$$

$$\Delta y_{i,t} = \alpha_i + \zeta_i\left(y_{i,t-1} - \acute{\omega}'_i x_{i,t-1}\right) + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta'^*_{ij} \Delta x_{i,t-j} + \tag{4}$$

$$+ \sum_{j=0}^{K} \varphi'_{ij} \overline{Z_{\iota,t-\jmath}} + \sum_{j=1}^{p-1} \psi_j \overline{\Delta y_{\iota,t-\jmath}} + \sum_{j=0}^{q-1} \zeta_j \overline{\Delta x_{\iota,t-\jmath}} + \varepsilon_{it}$$

4. Results and analysis

The assessment of cross-sectional dependence (CSD) was conducted at the beginning of the study, and Table 2 presents the results of the cross-sectional dependence test. The null hypothesis, which states that there is no cross-sectional dependence among the units, is rejected based on the test findings. This indicates that there is no cross-sectional or inter-country independence among our indicators.

Table 2: The results of the cross- sectional dependence

Cross- sectional dependence	Breusch- Pagan LM
LEF	1225.24
LGDP	1890.22
LURB	2335.82
LTOUR	1364.54
LRE	1867.88

Note: All *t* values are statistically significant at 1% level

Source: Authors' calculations

Table 3: Results of the panel unit root test

Variables	CADF	
	Level	1st Difference
LEF	-1.994	-4.198*
LGDP	-1.192	-2.792*
LURB	-2.26**	-2.752
LTOUR	-1.874	-2.962*
LRE	-2.24***	-4.37*

Note: *, ** and *** represent 1%, 5% and 10% level of significance, respectively

Source: Authors' calculations

Determining the integration properties of the variables involves applying a stationarity analysis (Ding et al., 2021). Conventional stationarity tests may yield biased results, as the residual terms encompass dependencies (Murshed & Dao, 2022). Therefore, the second-generation unit root test results presented in Table 3 are based on the assumption that all variables are integrated of order I(1), in order to confirm that the requirement of the proposed econometric technique regarding integration among variables is satisfied. Consequently, a homogeneity test, shown in Table 4 and proposed by Pesaran and Yamagata (2008), was also conducted. The results confirm the existence of slope parameter variations, supporting the findings of Li et al. (2021) and Acheampong (2019), since all variables showed statistically significant results.

Table 4: Heterogeneity analysis

Model	Pesaran and Yamagata (2008)		Blomquist and Westerlund (2013)	
$LEF_{it} = f(LGDP_{it}, LURB_{it}, LTOUR_{it}, LRE_{it})$	Delta	Adj. Delta	Delta	Adj. Delta
	16.61	18.57	11.80	13.20

Note: All computed values are significant at 1% level of significance

Source: Authors' calculations

To further verify whether the variables in the empirical analysis are cointegrated, cointegration tests were applied. Table 5 presents the results of Pedroni, Kao and Westerlund's cointegration test, which provide evidence of the existence of cointegration among the variables.

Table 5: Panel cointegration test

Panel EU-14 $LEF_{it} = f(LGDP_{it}, LURB_{it}, LTOUR_{it}, LRE_{it})$				
Test	Statistic	Value	Probability	Co-integration
Westerlund panel cointegration	Variance ratio	-2.3563	0.009	Yes
Pedroni panel cointegration	Modified Phillips- Perron t	-0.16	0.44	No
	Phillips- Perron t	-7.39	0.00	Yes
	Augmented Dickey- Fuller t	-7.54	0.00	Yes
Kao panel cointegration	Modified Dickey- Fuller t	-1.96	0.02	Yes
	Dickey- Fuller t	-1.86	0.03	Yes
	Augmented Dickey- Fuller t	-1.14	0.13	No

Source: Authors' calculations

Table 6 summarizes the results obtained using this procedure. The next step is to determine the coefficient values for both long-term and short-term scenarios. In this study, the CS-ARDL method is used to achieve this goal. The CS-ARDL approach accounts for cross-sectional dependence in panel data series, ensuring robust results. The findings from the CS-ARDL approach are presented in Table 6.

Table 6: CS-ARDL model result

	Short- run results		Long- run results	
	Coefficient	P value	Coefficient	P value
LGDP	0.86	0.00	0.77	0.00
LURB	0.94	0.04	1.39	0.03
LTOUR	-0.04	0.04	-0.04	0.03
LRE	0.01	0.94	-0.09	0.05

Source: Authors' calculations

The study's results indicate that EU countries emit more emissions as a consequence of higher economic growth and urbanization rates. A 1% increase in economic growth leads to a 0.86% rise in emissions in the short term, while a 1% change in economic growth in the long term increases emissions by 0.77%. A 1% increase in the urbanization rate results in a 0.94% rise in emissions in the short term, and a 1% change in the urbanization rate in the long term increases emissions by 1.39%. Similar results were obtained by Raihan (2023). A 1% development in the tourism sector leads to a 0.04% decrease in emissions in both the short and long term. Additionally, the results of Satrovic and Muslija (2019) indicate a positive but decreasing impact of urbanization on emissions.

The findings of this study also point to a high level of environmental awareness among citizens in the top ten most visited tourist destinations. Purwono et al. (2024) reveal the existence of an inverted N-shaped relationship between tourism and emissions, indicating an initial decrease in CO_2, followed by an increase as the sector matures, and a final decline. The study emphasizes the importance of controlling urbanization to mitigate CO_2 emissions. In analysing OECD countries, Alola et al. (2021) showed that the impact of international tourist arrivals and urbanization is statistically significant and harmful to environmental quality across the quantile spectrum, though slightly diminished in the upper quantile. Raihan and Tuspekova (2022) demonstrated that urbanization and tourism cause environmental degradation by increasing emissions in Brazil. Similar results were obtained by Raihan et al. (2022) for Argentina. Moreover, Bin Amin and Aftabi Atique (2021) identified a unidirectional causal relationship from urbanization to CO_2 emissions.

Policymakers should prioritize the adoption of renewable energy sources to meet the growing energy demands associated with rapid tourism development in the early stages. As tourism sectors mature, the focus should shift toward maintaining CO_2 reductions through active promotion and investment in renewable energy integration. Urbanization policies should be designed with a focus on sustainable practices to mitigate negative externalities. Furthermore, laws should promote green urban innovation and the development of smart buildings. EU governments can enhance economic growth without harming the environment by prioritizing green and sustainable urbanization. Urban development initiatives must emphasize energy efficiency, technological innovation, and sustainable lifestyles, as rapid urbanization harms ecosystems. Authorities can encourage sustainable and green urbanization, which would increase the use of renewable energy sources, such as electric vehicles, energy-efficient lighting, ethanol for vehicles, and similar technologies, to reduce environmental damage. Renewable energy, along with energy-efficient devices and machinery in the workplace, can minimize urban energy consumption and carbon dioxide emissions.

5. Discussion

The empirical findings obtained in this study provide a clearer understanding of how tourism development, urbanization, economic growth, and renewable energy jointly shape environmental sustainability in the European Union. Although the estimated coefficients have already been presented in the previous section, their broader economic interpretation reveals several important implications.

First, the positive impact of economic growth on ecological footprint confirms that higher levels of production and consumption in EU countries continue to generate considerable pressure on natural resources. The estimated elasticities indicate that economic expansion still relies on intensive energy use, transport activity, and material consumption, despite the European Union's long-standing commitment to green transition. This result suggests that the process of decoupling growth from environmental degradation remains incomplete.

Second, urbanization appears as the long-run determinant of ecological footprint, which gives particular weight to the argument that spatial concentration of population and economic activities produces cumulative environmental costs. While urban development generally stimulates productivity, innovation, and service sector expansion, the obtained results indicate that these economic benefits are accompanied by rising demand for housing, transport infrastructure, municipal services, and energy-intensive urban lifestyles. Consequently, urbanization becomes a structural driver of ecological pressure when not managed through sustainable planning instruments.

A particularly interesting outcome of the analysis is the negative and statistically significant coefficient of tourism activity. Unlike the conventional assumption that tourism growth necessarily intensifies environmental degradation through higher mobility, accommodation demand, and resource use, the present study indicates that tourism in the European Union contributes to a modest reduction in ecological footprint. This suggests that the tourism sector in mature European destinations may increasingly operate under stronger environmental standards, including green certification, sustainable destination management, and greater ecological awareness among tourists and service providers. The current findings imply that tourism should not automatically be treated as an environmental burden, but rather as a sector whose ecological effect depends on the quality of governance and sustainability orientation.

The long-run role of renewable energy additionally strengthens this interpretation. Although its short-run effect is statistically weak, renewable energy consumption shows a negative long-run impact on ecological footprint, indicating that environmental gains from clean energy adoption materialize gradually. This confirms that renewable transition is a structural process rather than an immediate corrective mechanism. As renewable infrastructure expands and dependence on fossil fuels decreases, the ecological pressure generated by growth and urbanization can be partially mitigated. In this regard, the findings support the policy logic emphasized in previous environmental studies that long-term investment in clean energy remains essential for achieving sustainable growth outcomes.

Taken together, the results reveal an important duality in the EU development model. On the one hand, economic growth and urbanization continue to intensify ecological footprint, confirming the persistence of traditional environmentally costly development patterns. On the other hand, tourism and renewable energy emerge as potential mitigating channels capable of reducing part of that pressure. This integrated perspective represents the main contribution of the study, as it shows that environmental sustainability in the European Union depends less on limiting economic activity itself and more on transforming the way in which growth, tourism expansion, and urban development are managed.

From the standpoint of public policy, the discussion suggests several practical directions. EU governments should place stronger emphasis on green urban planning, energy-efficient buildings, sustainable public transport, and circular municipal infrastructure in order to reduce the long-term environmental burden of urban concentration. At the same time, tourism policy should continue to support eco-certified accommodation, low-carbon destination branding, and environmentally responsible tourism services, since the sector has the capacity to contribute positively under adequate regulation. Finally, continued investment in renewable energy sources remains indispensable if the environmental costs of growth are to be neutralized over time.

Overall, the discussion confirms that the ecological future of the European Union will largely depend on whether green adjustment mechanisms can progress faster than the environmental pressures generated by economic and urban expansion.

6. Conclusions

Cities have become central actors in the global response to climate change, as they concentrate both population growth and economic activity. With more than 56% of the world's population residing in urban areas, cities account for over 70% of global emissions, according to the United Nations. This dual role positions urban areas as both major contributors to environmental pressure and critical platforms for implementing sustainable solutions. In line with this global context, the empirical findings indicate that economic growth and urban expansion within the European Union remain key drivers of ecological degradation, as reflected in the rising ecological footprint. Tourism also represents a significant source of environmental pressure, accounting for approximately 8% of global emissions, with projections suggesting a substantial increase in emissions by 2030 compared to pre-pandemic levels. However, the ongoing recovery of tourism toward pre-COVID activity levels presents a critical window of opportunity to reshape the sector along more sustainable pathways.

The findings of this study provide empirical answers to the three research questions and allow for a broader evaluation of sustainable tourism transitions in the European Union. Concerning RQ1, which examined the short-run and long-run effects of tourism activity and urbanization on ecological footprint, the results confirm that both variables are statistically significant determinants of environmental sustainability, although their effects move in opposite directions. Urbanization emerged as a strong footprint-amplifying factor, indicating that continued spatial concentration of population, infrastructure expansion, and energy-intensive urban consumption generate persistent ecological pressure. Tourism activity, however, displayed a negative coefficient in both the short and long run, suggesting that tourism development in advanced European economies may increasingly operate through environmentally improved organizational practices, cleaner destination management, and stronger sustainability standards. Thus, RQ1 is confirmed by demonstrating that tourism and urbanization materially shape ecological footprint, but with fundamentally different environmental consequences.

With respect to RQ2, which asked whether renewable energy transitions can compensate for tourism- and urbanization-driven environmental pressures, the results indicate that such compensation is possible primarily over longer adjustment horizons. Although renewable energy consumption does not exhibit a statistically meaningful short-run corrective influence, its negative long-run coefficient confirms that the gradual substitution of conventional fossil-based systems contributes to reducing ecological demand over time. This means that renewable transition cannot instantly neutralize the environmental costs associated with growth and urban expansion, but it remains a crucial structural mechanism for long-term ecological stabilization. Accordingly, RQ2 is also empirically supported, with the qualification that the environmental returns of renewable investment are cumulative rather than immediate.

The answer to RQ3 is particularly important from a methodological and policy standpoint. After explicitly accounting for cross-country interdependence through second-generation panel procedures and CS-ARDL estimation, tourism dynamics in the European Union appear to be footprint-mitigating rather than footprint-amplifying in the long run. This result suggests that once common shocks, interconnected markets, and shared sustainability governance are incorporated into the analysis, tourism no longer emerges solely as a source of additional environmental burden. Instead, within highly regulated and institutionally mature economies, tourism seems increasingly compatible with ecological stabilization, likely because the sector is more rapidly exposed to green certification, low-carbon destination management, sustainable mobility solutions, and environmentally conscious consumer demand. Therefore, the study provides evidence that the long-run environmental sign of tourism is context-dependent and conditioned by the regulatory and technological framework in which tourism expansion takes place.

Beyond resolving the research questions, the study contributes to the literature in several important respects. It broadens the tourism–environment debate by relying on ecological footprint as a consumption-based sustainability indicator rather than limiting the analysis to territorial emissions alone. In addition, by combining tourism intensity, urbanization, economic growth, and renewable energy within a cross-sectionally augmented dynamic panel framework, the paper demonstrates that environmental sustainability in advanced economies cannot be explained through isolated sectoral relationships, but through the interaction of multiple development forces under shared institutional interdependence. In this sense, the research offers a more integrated empirical perspective on the structural conditions under which tourism can coexist with climate-neutrality objectives.

Nevertheless, the analysis is subject to several limitations. The sample includes fourteen EU countries and therefore cannot entirely reflect destination-level differences in tourism specialization, urban governance quality, or national ecological policy implementation. A sample of 14 EU countries may restrict generalizability of the findings, and reliance on aggregate national data overlooks important regional and destination-level heterogeneity. Furthermore, ecological footprint remains a broad synthetic measure that does not isolate the separate environmental contributions of transport, accommodation, food supply chains, or imported tourism consumption. These issues open important directions for future research, particularly through destination-specific panel studies, nonlinear threshold modelling, and comparative assessments of alternative tourism structures within European urban systems.

The institutional implications of the results are substantial. Since urbanization remains the dominant long-run source of ecological pressure, EU sustainability strategies must move toward stricter green urban planning, compact infrastructure, energy-efficient construction, and low-carbon public mobility. At the same time, the environmentally mitigating role of tourism suggests that tourism policy should continue to support eco-certification, sustainable destination governance, and green innovation instead of viewing tourism expansion exclusively as an ecological threat. Finally, the long-run significance of renewable energy confirms that clean energy investment must remain one of the central instruments for absorbing the environmental costs of affluence and urban concentration. The broader conclusion is that ecological stabilization in advanced European economies will depend not on limiting tourism or development itself, but on the institutional capacity to synchronize tourism governance, urban transition, and renewable energy policy within a coherent sustainability framework.

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Turizam, urbani rast i ekološki otisak: Empirijski uvidi iz Europske unije

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Sažetak

Turizam, urbani rast i ekološka održivost sve su više međusobno povezani u Europskoj uniji, gdje brza urbana ekspanzija i gospodarska aktivnost intenziviraju ekološke pritiske. Razumijevanje načina na koji turizam djeluje unutar tih dinamika postalo je središnje pitanje rasprave o održivom turizmu, budući da kreatori politika i ostali dionici nastoje uskladiti gospodarski razvoj sa zaštitom okoliša. Ovo istraživanje ispituje kratkoročne i dugoročne učinke turističke aktivnosti, urbanizacije, gospodarskog rasta i potrošnje obnovljive energije na ekološki otisak u 14 zemalja Europske unije u razdoblju od 1995. do 2024. godine. Primjenom CS-ARDL modela (cross-sectionally augmented autoregressive distributed lag), koji uzima u obzir međusektorsku ovisnost i heterogenost nagiba, analiza potvrđuje postojanje dugoročne kointegracijske veze među varijablama. Rezultati pokazuju da gospodarski rast i urbanizacija značajno povećavaju ekološki otisak, dok međunarodni turizam ima ublažavajući učinak na pritiske na okoliš. Obnovljiva energija pridonosi ekološkom poboljšanju u dugom roku, iako je njezin kratkoročni učinak ograničen. Empirijski rezultati naglašavaju potrebu za integriranim politikama koji objedinjuju održivi razvoj turizma, urbano planiranje i strategije obnovljive energije unutar Europske unije. Istraživanje ističe važnost koordiniranog djelovanja urbanista, kreatora energetske politike i dionika u turizmu kako bi se poticao gospodarski rast uz istodobno osiguravanje okolišne održivosti za buduće generacije.

Ključne riječi: *održivi razvoj turizma, urbanizacija, procjena ekološkog otiska, okolišna održivost, usvajanje obnovljive energije, dinamika gospodarskog rasta, Europska unija*

JEL klasifikacija: *L83, Q56, R11*

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Enhancing Decision Support for Resource Allocation Through Markov Chain-Based Receivables Forecasting: A Robustness Analysis Using Monte Carlo Simulation*

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Abstract

Efficient resource allocation by individuals, firms, and society represents one of the central issues in economic theory and practice. The achievement of economic objectives depends on the ability to allocate scarce resources under uncertainty. Receivables collection forecasting contributes to more efficient and lower-risk resource allocation by supporting decisions regarding the future allocation of corporate assets. This study develops and applies a forecasting framework based on an absorbing Markov chain model, complemented by a Monte Carlo robustness analysis, to estimate collection probabilities, expected collection times, and projected cash inflows from receivables over both short- and long-term horizons. The proposed approach enables the quantification of collection dynamics and provides additional information for financial planning and investment decisions. The findings indicate that reliable receivables forecasting can improve asset allocation efficiency and reduce decision-making risk, thereby supporting improvements in corporate profitability.

Keywords: *accounts receivables forecasting, decision-making, energy industry, Markov chains, Monte Carlo simulation*

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1. Introduction

The early decades of the twenty-first century were characterized by increased market volatility and uncertainty, which heightened the risks associated with corporate resources allocation (Best, 2010; Bilan et al., 2019; Reinhart & Rogoff, 2009). The forecasting of financial indicators serves as a critical mechanism for ensuring market sustainability and enhancing the quality of managerial decision-making processes (Stanojević et al., 2017; Shmueli et al., 2019). In accordance with fundamental economic principles, economics examines how individuals, companies, and societies allocate their limited resources, which must be used efficiently because of their scarcity (Mankiw, 2021).

The allocation of a firm's limited resources is closely related to both short-term and long-term receivables, which are generated through the sale of goods and services (Hill et al., 2010; García-Teruel & Martínez-Solano, 2010). The allocation of limited capital is enhanced by forecasting the total amount of receivables expected to be collected or written off in the future (Keyser et al., 2025). Consequently, forecasting the dynamics of collectible and uncollectible receivables supports more effective investment decision-making processes and contributes to improved business performance (Aktas et al., 2015; Keyser et al., 2025).

The distinction between deterministic and stochastic processes is essential to predictive modelling and decision-making under current market conditions (Janssen at al., 2013; Ross, 2014; Grimmett & Stirzakar, 2020). Deterministic models cannot adequately represent stochastic processes because they do not account for inherent randomness (Rüschendorf, 2023). The evolution of variables according to predictable pattern belongs to the domain of deterministic processes (Ross, 2014; Jansssen et al., 2013). In contrast, stochastic processes involve inherent uncertainty, and their evolution cannot be predicted with certainty (Laurence, 2017).

Predictive modelling may be based on discrete or continuous time. Stochastic processes include both discrete and continuous variables (Bas, 2019). Markov processes have been applied to predict variable behaviour over discrete or continuous intervals (Gagniuc, 2017). Forecasting variable trends supports more informed and lower-risk decision-making (Stojić et al., 2019). Accounts receivable from customers play a crucial role in firms' liquidity and working capital management (Hill et al., 2010; Yao & Deng, 2018). The company's liquidity is largely determined by the collectability of these receivables (Michalski, 2008). Thus, the analysis of receivables as a balance sheet item becomes both a subject of theoretical economics and a critical component of the decision-making process (García-Teruel & Martínez-Solano, 2010).

Receivables collection is influenced not only by internal managerial decisions but also by external market factors encountered by individuals and firms (Bougheas et al., 2009; Ferenčak et al., 2018). The process of allocating limited company resources is enhanced through accurate forecasting and effective management of receivables (Tangsucheeva & Prabhu, 2014). Efficient resource management directly contributes to the optimization of a firm's profitability (Maritan & Lee, 2017). Accordingly, this study develops an absorbing Markov-chain model to estimate future collection probabilities, expected collection times, and receivables collectability, thereby supporting more efficient resource allocation and corporate decision-making.

2. Theoretical background

The theoretical background of this research is grounded in the concept of Markov chains, relevant scientific theories, and applied forecasting models. This section outlines the proposed conceptual framework and research hypotheses. It also provides a theoretical overview of the application of Markov models to forecast the collectability of corporate receivables. The fundamental assumptions underlying Markov processes are discussed, as these must be satisfied to ensure robust forecasting of balance sheet positions and to support more accurate and insightful financial analysis.

Markov chains represent an idealized structure that effectively captures the relationship between different variables (Bäuerle & Rieder, 2011). These models are stochastic in nature because future transitions are governed by probability distributions rather than deterministic rules (Pardoux, 2008; Meyn & Tweedie, 2012). The proposed models are based on current probabilities to predict the realization of future movements in the values of the observed variables (Levin & Peres, 2017). The core principle of Markov processes is that future changes in variable values depend solely on their current values, without reference to past values (Tolver, 2016). The analysis and prediction of future variable movements are carried out based on the current values of those variables, without consideration of their historical trajectories (Davis, 2018). By applying Markov models and interpreting the resulting data, corporate decision-makers are able to support strategic choices that significantly influence the short-term operational success of the company (Nguyen, 2018; Tian & Shen, 2019). Variations in balance sheet positions and the overall effectiveness of business policies depend heavily on managerial proactivity and the ability to accurately forecast the collectability of receivables over the short- and long-term horizons (Aktas et al., 2015; Keyser et al., 2025). To support future investment decisions and enhance the quality of financial planning, this study develops a predictive model to estimate the future collectability of firm receivables.

The receivables position in the balance sheet includes the categories of *internal account collections* and *delivery of value*. Internal collections include advance payments to suppliers, salary advances, short-term investments, and advance payments of liabilities owed by the company (Kang et al., 2019; Kieso et al., 2025). The receivables position is observed in the balance sheet and is defined as an accounting term for money owed to a company for goods and services previously delivered, but not yet paid for (Kieso et al., 2025). The measure of a company's business success is reflected in the value of individual positions in the balance sheet and the income statement (Rutkowska-Ziarko & Pyke, 2017). Return on assets (ROA), return on investment (ROI), and return on equity (ROE) are widely used profitability measures for evaluating financial performance and firm value (Tantra et al., 2019). Enhancing the decision-making process and improving the allocation of resources are supported through forecasting the total collectability of receivables or the potential need for their write-off (Omerašević & Selimović, 2020; Zdeněk et al., 2024). Markov process modelling represents an effective method for forecasting the collectability of corporate receivables (Keyser et al., 2025). Corporate receivables management policies should be adapted to changes in firms' operating and financial environments, including customer credit risk and financing conditions (Michalski, 2008; Bougheas et al., 2009; Hill et al., 2010). Namely, receivables management requires monitoring of credit terms, accounts receivable levels, and financing conditions to support liquidity and efficient working capital management (Bougheas et al., 2009; García-Teruel & Martínez-Solano, 2010).

Decision-making based on intuition is reduced through more precise forecasting of the future movements of financial variables (Tenyakov, 2014). To predict future states of the system, current probabilities of receivables collection are calculated. Given the dynamic nature of the system, a transition probability matrix is formed, with element values calculated to represent transitions between time intervals (Sericola, 2013). The rows and columns of the transition probability matrix correspond to possible system states and reflect how the system evolves over time. A fundamental assumption of the Markov chain is that the various states of the observed system are mutually exclusive. Accordingly, the system can occupy only one state at any given moment and cannot exist in multiple states simultaneously (Grimshaw & Alexander, 2011).

Here is an overview of the basic assumptions underlying Markov models for reliable forecasting and financial analysis (Norris, 1998; Ross, 2014; Kulkarni, 2016):

1) The state of the system at a given time depends solely on its state at the immediately preceding time point.

2) There is a finite and identifiable set of possible system states, which serves as the basis for constructing the forecasting model.

3) The states of the observed system are mutually exclusive, implying that the system can occupy only one state at any given time.

4) The transition probability matrix, which is specific to each Markov chain, is assumed to be stationary, meaning that it remains constant throughout the observed period.

Since the early 20th century, a significant number of studies have examined the application of Markov processes in finance and theoretical economics (Douc et al., 2018). Financial forecasting is conducted over both discrete and continuous time intervals, based on the analysis of current financial indicators (Davis, 2018). Depending on the nature of the time dimension, different types of Markov processes are distinguished. Markov chains are classified into two groups: discrete time and continuous-time Markov chains (Levin & Peres, 2017; Rüschendorf, 2023).

According to Sericola (2013), discrete-time Markov processes include models such as Random Walks on the Number Axis and the Gambler's Ruin problem. In contrast, continuous-time Markov processes include models such as Brownian Motion and the Poisson Point Process (Morozov & Skripkin, 2011). These models have found broad application across a range of scientific disciplines, including ecology, biology, chemistry and physics (Walter, 2021).

Based on the previously discussed theoretical concepts, and in alignment with the subject matter of this scientific research, the following research hypotheses are proposed:

> H1: *Forecasting the future movement of corporate receivables using an absorbing Markov-chain model, completed by Monte Carlo simulation, improves managerial decision-making and enhances the efficiency of resource allocation processes.*
>
> H2: *The application of predictive models for estimating the collectability of corporate receivables contributes to reducing risk in decisions regarding the future allocation of investment capital.*

In this study, two hypotheses are proposed and will be tested primarily using the absorbing Markov-chain model, while Monte Carlo simulation is employed as a complementary robustness analysis. The focus of this research is based on the premise that the application of economic-mathematical models to predict the collectability of corporate receivables reduces managerial decision-making risk and mitigates subjectivity in investment decisions. The research aims to test the thesis that the application of economic-mathematical models for forecasting corporate receivables enhances the decision-making process and optimizes resource allocation in future business cycles.

3. Mathematical definition of Markov models

This section provides an economic-mathematical definition of Markov processes, outlining the essential elements required for the construction of the proposed model. The development of the Markov model involves calculating the Markov transition probability matrix, which serves as the fundamental component of the Markov chain. Therefore, the prediction of the future states of corporate receivables is conducted based on the current state of the system and the values contained in the transition probability matrix.

The theoretical framework assumes that, for the purposes of determining the initial and future states of a Markov process, the system is represented by state vectors defined in a precisely specified form (Davis, 2018). The symbol S(t) is used for the state vector of the system at period t, while the symbol $S_n(t)$ refers to the state of the system in a future period. The state of the system in the initial period for predicting future system states is determined through the system state vector in period t, as well as the probabilities of transitioning to one of the n possible states (Bäuerle & Rieder, 2011).

$$\mathrm{S(t)} = (\mathrm{S_1(t)}, \mathrm{S_2(t)}, \mathrm{S_3(t)}, \mathrm{S_4(t)}, \ldots, \mathrm{S_n(t)}) \tag{1}$$

To describe transitions from the current to the future state of the system over two consecutive periods, a Markov transition probability matrix is constructed (Gagniuc, 2017). The probability of transitioning from one state of the system to another determines the values of the matrix elements (Levin & Peres, 2017). The matrix is denoted by the symbol (T). Matrix (T) represents the conditional probability of transitioning from the current state to the future state during the period (t, t + 1). The Markov transition probability matrix (T) constitutes the fundamental element of the Markov chain (Grimshaw & Alexander, 2011):

$$\mathrm{T} = \begin{bmatrix} T_{11} & T_{12} & T_{13} & T_{14} & \ldots & T_{1n} \\ T_{21} & T_{22} & T_{23} & T_{24} & \ldots & T_{2n} \\ T_{31} & T_{32} & T_{33} & T_{43} & \ldots & T_{3n} \\ T_{41} & T_{42} & T_{43} & T_{44} & \ldots & T_{4n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ T_{n1} & T_{n2} & T_{n3} & T_{n4} & \ldots & T_{nn} \end{bmatrix} \tag{2}$$

The Markov transition probability matrix (T) contains all the probabilities of the system transitioning between different states in the initial and future periods (Bäuerle & Rieder, 2011). The probabilities on the main diagonal (T_{11}, T_{22}, T_{33}, T_{44}, ..., T_{nn}) indicate the probability that the system remains in the same state after the end of the period (t, t + 1).

The probabilities within the rows of the matrix (T_{n1}, T_{n2}, T_{n3}, T_{n4}, ..., T_{nn}) and the probabilities within the columns of the matrix (T_{1n}, T_{2n}, T_{3n}, T_{4n}, ..., T_{nn}) refer to the probabilities of transitions between system states during the period (t, t + 1).

The main diagonal of the Markov transition probability matrix contains the probabilities that the system remains in the same state, while the sum of the probabilities in each row is equal to one. Thus, the transition probability matrix satisfies the normalization condition (Grimshaw & Alexander, 2011).

$$\begin{gathered}\sum_{f=1}^{n}(T_{cf} = 1) \qquad \text{for each } c = 1,2,3,4, \ldots, n \\ 0 \leq T_{cf} \leq 1\end{gathered} \tag{3}$$

The current state of the system and the values of the Markov transition probability matrix are used to predict future system states (Hirsa & Neftci, 2013):

$$\begin{aligned} S_{(t+1)} &= S_{(t)}T \\ S_{(t+2)} &= S_{(t+1)}T = S_{(t)}T^2 \\ S_{(t+3)} &= S_{(t+2)}T = S_{(t)}T^3 \\ &\ldots \\ S_{(t+L)} &= S_{(t+(L-1))}T = S_{(t)}T^L \end{aligned} \tag{4}$$

The process of predicting future states of a system does not require information about the past values of the variables. Instead, predictions are made based on the current state of the system (Tolver, 2016). Therefore, the equilibrium state of the system is determined by multiplying the system state vector and the Markov transition probability matrix (T):

$$S(E) = S(E)T \tag{5}$$

In the empirical part of the research, the equilibrium state of the system is determined using a system of equations and the Markov transition probability matrix (T) (Ross, 2014; Kulkarni, 2016; Stojić et al., 2019):

$$\begin{gathered}(E) = \big(S_1(E), S_2(E), S_3(E), S_4(E), \ldots, S_n(E)\big)T \\ \big(S_1(E), S_2(E), S_3(E), S_4(E), \ldots, S_n(E)\big) \begin{bmatrix} T_{11} & T_{12} & T_{13} & T_{14} & \cdots & T_{1n} \\ T_{21} & T_{22} & T_{23} & T_{24} & \cdots & T_{2n} \\ T_{31} & T_{32} & T_{33} & T_{34} & \cdots & T_{3n} \\ T_{41} & T_{42} & T_{43} & T_{44} & \cdots & T_{4n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ T_{n1} & T_{n2} & T_{n3} & T_{n4} & \cdots & T_{nn} \end{bmatrix} = \\ (S_1(E), S_2(E), S_3(E), S_4(E), \ldots, S_n(E))\end{gathered} \tag{6}$$

If the previously presented system of equations for “S_j(E)” is simplified, its solution yields the equilibrium state of the system:

$$S_j(E) = S_j$$

$$S_1 = S_1T_{11} + S_2T_{21} + S_3T_{31} + S_4T_{41} + \ldots + S_nT_{n1}$$

$$S_2 = S_1T_{12} + S_2T_{22} + S_3T_{32} + S_4T_{42} + \ldots + S_nT_{n2}$$

$$S_3 = S_1T_{13} + S_2T_{23} + S_3T_{33} + S_4T_{43} + \ldots + S_nT_{n3}$$

$$S_4 = S_1T_{14} + S_2T_{24} + S_3T_{34} + S_4T_{44} + \ldots + S_nT_{n4}$$

$$\ldots$$

$$S_n = S_1T_{1n} + S_2T_{2n} + S_3T_{3n} + S_4T_{4n} + \ldots + S_n T_{nn}$$

subject to the following condition:

$$\sum_{j=1}^{n} S_J = 1 \qquad (7)$$

Based on the set of equations for S_j and a precisely defined transition probability matrix, the equilibrium state of the system is determined (Tolver, 2016). The final result is calculated using the Markov chain model. The current and future states of the system are identified, as well as the probabilities of transitioning from the current to the future state of the system (Tian & Shen, 2019).

In the next iteration, the current state of the system is transformed through the Markov transition probability matrix to determine the future system state. According to Siekelova et al. (2019), the results of Markov processes are represented by the probabilities of transitions between different system states, while their analysis leads to the determination of the equilibrium-state probabilities and predictions of future receivables collectability.

This section has presented the mathematical formulation of the absorbing Markov chain model has been presented to predict the direction and intensity of changes in the value of corporate receivables in future periods. The collectability and non-collectability of receivables are estimated using the Markov transition probability matrix, the fundamental Markov matrix, and the absorption probability matrix. Therefore, the Markov model provides an analytical framework for supporting managerial decision-making and improving resource allocation under uncertainty.

4. Methodology and data

This section presents the sampling methods and data collection process, along with the key methodological tools used in this study. The analytical framework section is based on an absorbing Markov-chain model, while Monte Carlo simulation is employed as a complementary robustness analysis. The development of the analytical Markov-chain model begins with the construction of the transition probability matrix, followed by the formation of the fundamental matrix and the calculation of the absorption probability matrix. Based on the elements of the resulting matrices, forecasts of the collectability of corporate receivables are generated for future periods.

4.1. Sampling methods and data collection process

The empirical part of this research is based on data collected from the balance sheets of a leading company in the field of electrification, automation, and digitalization. The selected company holds a dominant market position in the production of energy-efficient technologies designed to support the conservation of natural resources. A review of the financial statements indicates that the company has a significant market share in the production and transmission of electricity across different countries. The company is headquartered in Berlin, Germany, and operates in more than 190 countries, with approximately 377,000 employees (Siemens AG, 2017). The company pursues competitive advantage by adapting its marketing strategy to local market conditions while maintaining a globally consistent brand identity (Zou & Cavusgil, 2002). The company maintain its market position through investments in research and development, frequent product innovations, and a strong focus on product quality, improved decision-making, and efficient resource allocation (Barney, 1991; Teece, 2007).

For the empirical analysis, the analytical model is constructed using the financial results of one of the company's subsidiaries operating within the Serbian energy sector. Forecasting the amount of receivables to be collected and the subsequent allocation of company assets are carried out based on the balance sheet positions representing the current state of the system through the application of the absorbing Markov-chain model (Davis, 2018). The decision-making process and resource allocation based solely on current balance sheet positions and insights from financial statements are often insufficient for effective managerial decision-making (Collier, 2015). The probability of receivables collection and the Markov transition probability matrix represent the key elements required for the development of an economic-mathematical model (Hirsa & Neftci, 2013).

In the subsequent methodological stage of the research, the fundamental matrix and the absorption probability matrix are derived. Based on the estimated transition probabilities, the transition probability matrix is constructed (Grimshaw & Alexander, 2011). The estimated transition probabilities constitute analytical basis for the absorbing Markov-chain model. The complete set of transition probabilities is used to construct the analytical Markov-Chain model, whereas the transition probabilities directly associated with receivables collection are subsequently employed as input parameters in the Monte Carlo robustness analysis.

Table 1: Overview of the estimated transition probabilities used in the Markov chain model

Receivables from domestic customers		Symbol	Probability
Probabilities of receivables collection within one year from domestic customers			
1.	Probability of receivables collection within one year	T_{51}	23%
2.	Probability of non-collection of receivables within one year	T_{52}	18%
Probabilities of receivables collection over one year from domestic customers			
3.	Probability of receivables collection over one year	T_{61}	38%
4.	Probability of non-collection of receivables over one year	T_{62}	12%
Receivables from foreign customers		Symbol	Probability
Probabilities of receivables collection within one year from foreign customers			
1.	Probability of receivables collection within one year	T_{73}	28%
2.	Probability of non-collection of receivables within one year	T_{74}	15%
Probabilities of receivables collection over one year from foreign customers			
3.	Probability of receivables collection over one year	T_{83}	36%
4.	Probability of non-collection of receivables over one year	T_{84}	14%

Note: Foreign customers - customers located in foreign markets to whom the company exports and sells its products

Source: Authors' calculation based on the financial statements obtained from the Serbian Business Registers Agency (SBRA)

The probabilities of receivables collection from domestic and foreign customers over short- and long-term horizons, together with the probabilities of receivables retention and transitions between receivables due within one year and those due after more than one year, constitute the elements of the transition probability matrix (Table 2). Based on the probabilities presented in Tables 1 and 2, a transition probability matrix is constructed, and its elements are used to forecast the amount and temporal dynamics of receivables collection for the selected company.

Table 2: Retention and transition probabilities between receivables due within one year and receivables due after more than one year

Domestic customer receivables		Symbol	Probability
Retention and transition probabilities of domestic customer receivables			
1.	Retention of receivables up to one year	T_{55}	18%
2.	Transition from receivables up to one year to receivables over one year	T_{56}	41%
3.	Retention of uncollected receivables over one year	T_{66}	50%
Foreign customer receivables		Symbol	Probability
Retention and transition probabilities of foreign customer receivables			
1.	Retention of receivables up to one year	T_{77}	15%
2.	Transition from receivables up to one year to receivables over one year	T_{78}	43%
3.	Retention of uncollected receivables over one year	T_{88}	50%

Notes: *Data are derived from the annual financial statements obtained from the Serbian Business Registers Agency (SBRA) and are based on the balance sheet items reported as receivables from domestic customers due within one year, receivables from foreign customers due within one year, receivables from domestic customers due after one year, and receivables from foreign customers due after one year

**Foreign customers refer to customers located in foreign markets to whom the company exports and sells its products

Source: Authors' calculation of retention and transition probabilities based on the financial statements obtained from the Serbian Business Registers Agency (SBRA)

In the first part of the methodological framework, forecasting of receivables collection from domestic and foreign customers will be conducted through the construction of the Markov transition probability matrix (T_{ij}), the fundamental matrix (F) and the absorption probability matrix (K). Based on this approach, an absorbing discrete Markov-chain model with a finite state space is defined, and the Markov transition probability matrix (T_{ij}) is specified.

A discrete Markov chain is defined as a stochastic process (Norris, 1998; Gallager, 2013; Kulkarni, 2016):

$$\{X_t\}_{t\geq 0} \tag{8}$$

where the random variable X_t represents the state of the system at time t, with a finite state space (Norris, 1998; Gallager, 2013; Ross, 2014):

$$S = \{S_1, S_2, \cdots, S_8\} \tag{9}$$

Such a process is characterized by the following Markov-chain model property (Norris, 1998; Ross, 2014):

$$P(X_{t+1} = j \mid X_t = i, X_{t-1}, \dots, X_0) = P(X_{t+1} = j \mid X_t = i) \tag{10}$$

which implies that the future state of the system depends solely on the current state of the system, while previous states have no influence on the distribution of future state transitions (Gallager, 2013; Ross, 2014). More precisely, the conditional probability of transition from the current state to a future state is influenced only by the current state of the system, while previous states are not taken into account (Kulkarni, 2016).

The transition probability matrix of the model is defined as follows:

$$T = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ T_{51} & T_{52} & T_{53} & T_{54} & T_{55} & T_{56} & T_{57} & T_{58} \\ T_{61} & T_{62} & T_{63} & T_{64} & T_{65} & T_{66} & T_{67} & T_{68} \\ T_{71} & T_{72} & T_{73} & T_{74} & T_{75} & T_{76} & T_{77} & T_{78} \\ T_{81} & T_{82} & T_{83} & T_{84} & T_{85} & T_{86} & T_{87} & T_{88} \end{bmatrix}$$

where each element of the transition matrix represents a conditional transition probability defined by the following expression (Norris, 1998; Ross, 2014):

$$T_{ij} = P(X_{t+1} = j \mid X_t = i) \tag{11}$$

where (T_{ij}) denotes the probability of transition from system state (i) to system state (j) during a single time period (Norris, 1998; Kulkarni, 2016).

In constructing the Markov transition probability matrix, the following condition applies to each individual row of the matrix:

$$\sum_{j=1}^{8} T_{ij} = 1 \tag{12}$$

which implies that the normalization condition requires the sum of all possible transitions from one system state to all posible future states to be equal to one. Furthermore, the Markov transition probability matrix is a matrix of conditional probabilities (Norris, 1998; Ross, 2014). Following the construction of the Markov transition probability matrix, each row of the matrix is analyzed to estimate the collectability of customer receivables, and identify the risk of receivables transitioning into categories with longer maturities, and assess the probability of uncollectible receivables (Norris, 1998; Kulkarni, 2016).

The fifth row of the Markov transition probability matrix (T_{ij}) specifies the transition probabilities of short-term domestic customer receivables with maturities of up to one year. Its elements represent the probabilities of collection, retention within the same category, or transition to receivables with longer maturities. The sixth row of the Markov transition probability matrix (T_{ij}) specifies the transition probabilities of short-term foreign customer receivables with maturities of up to one year. The elements of this row represent the probabilities of collection of short-term foreign customer receivables or their transition to receivables with longer maturities. The seventh row of the Markov transition probability matrix (T_{ij}) specifies the transition probabilities of domestic customer receivables with maturities exceeding one year. The elements of the seventh row represent the probabilities of retention within the same receivables category or transition to the category of uncollectible receivables. The eighth row of the Markov transition probability matrix (T_{ij}) specifies the transition probabilities of long-term foreign receivables, including retention within the same category or transition to uncollectible receivables.

Using the transition probability matrix (B), the fundamental matrix is defined as follows (Kemeny & Snell, 1976; Norris, 1998):

$$F = (I - B)^{-1} \tag{13}$$

Alternatively, the fundamental matrix can be expressed as an infinite series:

$$F = I + B + B^2 + B^3 + \cdots \tag{14}$$

The condition for the existence of the fundamental matrix is defined as:

$$\rho(B) < 1 \tag{15}$$

where ρ(B) denotes the spectral radius of matrix (B) (Kulkarni, 2016).

The elements of the fundamental matrix are defined as:

$$n_{ij} = \mathbb{E}[\text{number of visits to state } S_j \mid X_0 = S_i] \tag{16}$$

where (n_{ij}) denotes the expected number of visits to the transient state (S_j) prior to absorption, given that the process starts in state (S_i) (Norris, 1998; Kulkarni, 2016).

The vector of expected absorption times is defined by the following expression:

$$t = F1 \tag{17}$$

where:

$$1 = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \tag{18}$$

The individual elements of the expected absorption time vector are expressed as follows (Grinstead & Snell, 2012; Kulkarni, 2016):

$$t_i = \sum_j n_{ij} \tag{19}$$

where t_i denotes the expected number of steps until absorption, given that the process starts in state (S_i). Based on the fundamental matrix, the absorption probability matrix is determined (Kemeny & Snell, 1976; Grinstead & Snell, 2012):

$$K = F \cdot A \tag{20}$$

where the matrix is obtained as the product of (F) and (A), with (A) containing transition probabilities from transient to absorbing states (Kulkarni, 2016).

To examine the robustness of receivables collection forecasts for domestic and foreign customers with maturities up to and over one year, Monte Carlo simulation is employed as a complementary stochastic analysis (Selto, 2020; Li, 2023).

The analytical Markov-chain model and the Monte Carlo simulation serve different methodological purposes. While the analytical model estimates the expected receivables collection by incorporating the complete transition matrix together with the absorption probabilities, the Monte Carlo simulation is based on the key transition probabilities associated with receivables collection (Glasserman, 2004; Selto, 2020). The Monte Carlo simulation is not intended to reproduce the complete Markov-chain process. Instead, it evaluates the variability of receivables collection outcomes under stochastic realizations of the selected transition probabilities.

The Monte Carlo simulation is performed using a 95% confidence interval and 10,000 simulation iterations. As input data, transition probabilities (T_{51}) and (T_{61}), together with the estimated receivables collected over a two-year period, are used for domestic customers. The same approach is applied to foreign customers using transition probabilities (T_{73}) and (T_{83}), together with the estimated receivables collected over the same period. The resulting empirical collection intervals provide a complementary assessment of the robustness of the analytical findings under stochastic variation in the selected transition probabilities.

4.2. Measurement

This section presents the methodological framework used to estimate the collectability of corporate receivables through the application of an absorbing Markov-chain model. Based on the estimated transition probabilities (T_{ij}), the Markov transition probability matrix is constructed and subsequently used to derive the fundamental matrix and the absorption probability matrix:

$$T = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0.23 & 0.18 & 0.00 & 0.00 & 0.18 & 0.41 & 0 & 0 \\ 0.38 & 0.12 & 0.00 & 0.00 & 0 & 0.50 & 0 & 0 \\ 0.00 & 0.00 & 0.28 & 0.15 & 0 & 0 & 0.15 & 0.43 \\ 0.00 & 0.00 & 0.36 & 0.14 & 0 & 0 & 0 & 0.50 \end{bmatrix} \text{(Transition Probability Matrix)}$$

The transition probability matrix is partitioned into the identity matrix (I), the transient-state transition matrix (B), and matrix (A), which contains the transition probabilities from transient to absorbing states.

$$I = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad B = \begin{bmatrix} 0.18 & 0.41 & 0 & 0 \\ 0 & 0.50 & 0 & 0 \\ 0 & 0 & 0.15 & 0.43 \\ 0 & 0 & 0 & 0.50 \end{bmatrix} \quad A = \begin{bmatrix} 0.23 & 0.18 & 0 & 0 \\ 0.38 & 0.12 & 0 & 0 \\ 0 & 0 & 0.28 & 0.15 \\ 0 & 0 & 0.36 & 0.14 \end{bmatrix}$$

The matrix difference (I – B) is given by:

$$I - B = \begin{bmatrix} 0.82 & -0.41 & 0.00 & 0.00 \\ 0.00 & 0.50 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.85 & -0.43 \\ 0.00 & 0.00 & 0.00 & 0.50 \end{bmatrix} \tag{21}$$

The fundamental matrix (F) is calculated as the inverse of the matrix difference between matrices (I) and (B):

$$F = (I - B)^{-1} \tag{22}$$

The resulting fundamental Markov matrix is obtained by substituting matrices (I) and (B) into Equation (22):

$$F = \left(\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.18 & 0.41 & 0 & 0 \\ 0 & 0.50 & 0 & 0 \\ 0 & 0 & 0.15 & 0.43 \\ 0 & 0 & 0 & 0.50 \end{bmatrix} \right)^{-1} \tag{23}$$

The resulting fundamental Markov matrix is presented in Equation (24):

$$\text{Fundamental Markov matrix (F)} = \begin{bmatrix} 1.21 & 1 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 1.17 & 1 \\ 0 & 0 & 0 & 2 \end{bmatrix} \quad (24)$$

The absorption probability matrix (K) is obtained by multiplying the fundamental matrix (F) by matrix (A), where matrix (A) contains the transition probabilities from transient to absorbing states:

$$K = F * A \quad (25)$$

The resulting absorption probability matrix is:

$$\text{Absorption probability matrix (K)} = \begin{bmatrix} 0.66 & 0.34 & 0 & 0 \\ 0.76 & 0.24 & 0 & 0 \\ 0 & 0 & 0.69 & 0.31 \\ 0 & 0 & 0.72 & 0.28 \end{bmatrix} \quad (26)$$

where each element K_{ij} satisfies $0 \leq K_{ij} \leq 1$, and represents the probability of eventual absorption into absorbing state (j), given that the process starts from transient state (i).

The first two rows of matrix (K) describe the absorption probabilities for receivables from domestic customers. Receivables due within one year are expected to be collected with a probability of 66%, whereas the probability of non-collection of receivables from domestic customers is 34%. For receivables with maturities exceeding one year, the estimated collection probability increases to 76%, whereas the probability of non-collection decreases to 24%.

The last two rows of matrix (K) present the absorption probabilities for receivables from foreign customers. Receivables due within one year are expected to be collected with a probability of 69%, while the probability of non-collection is 31%. For receivables from foreign customers with maturities exceeding one year, the probability of collection is estimated at 72%, whereas the probability of non-collection equals 28%.

5. Results and discussions

This section provides the results of the empirical analysis. The analytical findings obtained from the absorbing Markov-chain model are first presented, followed by a complementary Monte Carlo robustness analysis. The Markov-chain model provides the principal forecasts of receivables collectability, whereas the Monte Carlo simulation offers an additional assessment of the robustness of these forecasts under stochastic variation in the selected transition probabilities. The analysis continues by estimating the collectability of corporate receivables through the absorption probability matrix, which provides the probabilities of receivables collection within one year and beyond one year (Tian & Shen, 2019). Further analysis is conducted for receivables from domestic and foreign customers (Grimshaw & Alexander, 2011). Based on the financial statements of a company in the Serbian energy sector, the future probabilities of receivables collection and non-collection are estimated for domestic and foreign customers using the current balance sheet positions (Davis, 2018).

According to the company's annual financial report, obtained from the database of the Serbian Business Registers Agency (SBRA), the average receivables collection time was 89.25 days during 2021-2022. The company achieved strong business results, with an average receivables collection time of 73.12 days during 2020-2021. The elements of the fundamental matrix and the absorption probability matrix are used to predict the expected collection period for receivables from domestic customers and foreign customers. A comparative analysis is then performed to evaluate the difference between the observed average collection period and the expected collection period estimated by the Markov-chain model.

Table 3: Expected time required to collect receivables from both domestic and foreign customers

	Expected receivables collection	Period expressed in years and days	
Type of receivables	Time period for receivables collection	Number of years	Number of days
Receivables due within 1 year-domestic customers	1.219018717	1	79.94
Receivables over 1 year - domestic customers	2	2	
Receivables due within 1 year-foreign customers	1.176328116	1	64.35
Receivables over 1 year - foreign customers	2	2	

Source: Author's calculation, based on QM for Windows v5

The values presented in Table 3 indicate that receivables from domestic customers with a maturity of up to one year are expected to be collected within approximately one year and 80 days, with an estimated collection probability of 66%. Simultaneously, 34% of receivables are expected to remain uncollected and may subsequently be reclassified into the category of receivables with a maturity exceeding one year. Therefore, the obtained results suggest that a portion of short-term receivables may transition into the category of long-term receivables.

Receivables from domestic customers with a maturity exceeding one-year exhibit one year a collectability probability of 76% and an expected collection period of two fiscal years. Meanwhile, the estimated probability of non-collection is 24%, indicating that a proportion of receivables may remain outstanding for periods exceeding two years. The obtained findings provide useful information for managerial decision-making concerning future receivables management and resource allocation.

Regarding receivables from foreign customers, the results indicate that receivables with a maturity of up to one year are expected to be collected approximately one year and 64 days, with a collection probability of 69%. At the same time, 31% of receivables from foreign customers are expected to remain uncollected and may subsequently be transferred into the category of receivables with a maturity exceeding one year.

Receivables from foreign customers with a maturity exceeding one year demonstrate a collection probability of 72% and an expected collection period of two years, while the estimated probability of non-collection amounts to 28%. The obtained results indicate the existence of both collectible and non-collectible receivables within foreign markets, emphasizing the importance of forecasting receivables collection dynamics for reducing uncertainty in future business activities. The findings also provide additional support for managerial decision-making regarding the management and collection of outstanding receivables from foreign customers.

The empirical analysis further shows that receivables from domestic customers amounting to 2,440,687 thousand RSD are expected to be collected in the amount of 1,696,482 thousand RSD over short- and long-term periods, while the estimated uncollectible portion equals 744,205 thousand RSD. Additionally, receivables from foreign customers amounting to 258,900 thousand RSD are expected to be collected in the amount of 181,543 thousand RSD, whereas the uncollectible portion is estimated at 77,357 thousand RSD over both short- and long-term periods.

The empirical analysis requires a systematic classification of corporate receivables based on the customer type, collection status, and maturity structure. The categories used in the empirical analysis are presented in Table 4.

Table 4: Classification of corporate receivables by category and customer type

	Categories of company receivables	Obligation fulfilment
1	Collected receivables from domestic customers	yes
2	Uncollected receivables from domestic customers	no
3	Collected receivables from foreign customers	yes
4	Uncollected receivables from foreign customers	no
5	Receivables with a maturity of up to one year from domestic customers	less < 1
6	Receivables with a maturity over one year from domestic customers	more > 1
7	Receivables with a maturity of up to one year from foreign customers	less < 1
8	Receivables with a maturity over one year from foreign customers	more > 1

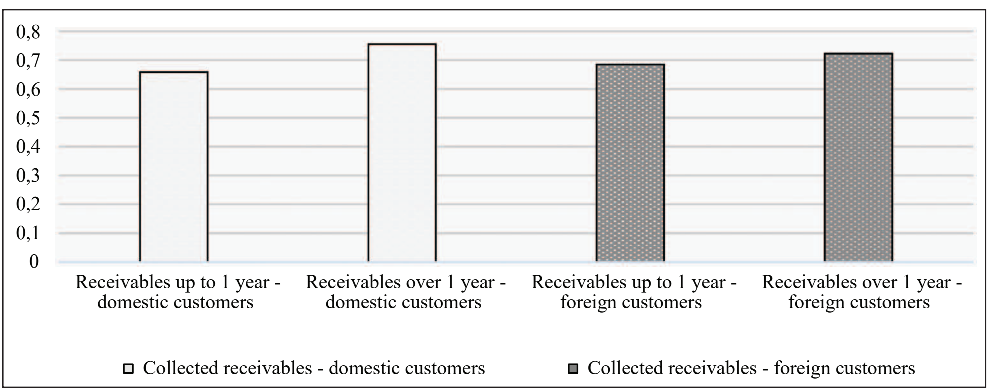
Source: Authors' classification of receivables by category based on financial statements, obtained from the Serbian Business Registers Agency (SBRA)

In the continuation of the research, the vector *v* represents receivables collected within one year and receivables collected after one year, while the matrix K represents the absorption probability matrix. If the final results of the research are denoted by R, then the following matrix expression is obtained:

$$\text{Absorption probability matrix (K)} = \begin{bmatrix} 0.66 & 0.34 & 0 & 0 \\ 0.76 & 0.24 & 0 & 0 \\ 0 & 0 & 0.69 & 0.31 \\ 0 & 0 & 0.72 & 0.28 \end{bmatrix}$$

$$\text{R} = \text{Vektor } (v) * \text{Absorption probability matrix (K)} \tag{27}$$

Figure 1: Receivables Collection Forecasts from Domestic and Foreign Customers



Note: The figure presents a comparison of receivables collection from domestic and foreign customers for receivables due within one year and receivables due after more than one year.

Source: Authors' elaboration

The analysis of the results obtained from the matrix (R), which reflects the degree of collectability of receivables in the future period, provides the following implications:

For domestic customers, the balance sheet item representing receivables due within one year amounts to 1,519,421 thousand RSD. The model predicts that receivables from domestic customers in the amount of 1,000,698 thousand RSD will be collected, while 518,723 thousand RSD is expected to remain uncollectible. Receivables from domestic customers with a maturity exceeding one year amount to 921,266 thousand RSD, of which 695,784 thousand RSD is expected to be collected beyond one year, while 225,482 thousand RSD is estimated to remain uncollectible.

For foreign customers, receivables with a maturity of up to one year amount to 147,161 thousand RSD. The obtained results indicate that 100,080 thousand RSD of receivables from foreign customers will be collected within this period, while 46,361 thousand RSD is expected to remain uncollectible. Furthermore, receivables from foreign customers with a maturity exceeding one year amount to 111,739 thousand RSD, of which 80,742 thousand RSD is forecast to be collected beyond one year, whereas 30,997 thousand RSD will remain uncollectible.

By modelling the receivables collection rate, managers may more accurately forecast the total resources available for future allocation. Consequently, forecasting cash flow dynamics through receivables collection contributes to more efficient allocation of limited company resources and supports managerial decision-making. As a complementary robustness analysis, Monte Carlo simulation was applied to evaluate the variability of receivables collection outcomes under stochastic realizations of the selected collection probabilities. The simulation was not intended to reproduce the complete analytical Markov-chain model but to assess the variability of receivables collection outcomes under stochastic realizations of the selected transition probabilities.

The forecasting of the receivables collection interval was conducted using Monte Carlo simulation, incorporating a 95% confidence level. The simulation was based on the transition probabilities of 23% for receivables due within one year and 38% for receivables due beyond one year. The resulting empirical distribution of simulated collection outcomes produced an estimated collection interval ranging from 1,640,722 thousand RSD to 1,644,764 thousand RSD.

The forecasting of the collection interval for receivables from foreign customers was also conducted using Monte Carlo simulation with a 95% confidence level. The simulation was based on the transition probabilities of 28% for receivables due within one year and 36% for receivables due beyond one year. The resulting empirical distribution of simulated collection outcomes produced an estimated collection interval ranging from 174,066 thousand RSD to 174,468 thousand RSD.

To examine the accuracy of forecasting balance sheet positions, the company's operational results were analysed using financial reports published during 2022 and 2023. The predictive validity of the developed model was tested by comparing the forecasted values against the company's balance sheet and income statement data for the two fiscal years following the forecast period.

According to the financial reports for 2022, the company collected receivables from domestic customers due within one year amounting to 1,084,438 thousand RSD. The financial reports for 2023 indicate that receivables collected from domestic customers due beyond one year amounted to 1,750,108 thousand RSD. Furthermore, the company's 2022 financial reports indicate that receivables collected from foreign customers due within one year amounted to 154,474 thousand RSD.

The company's financial statements for 2023 indicate that the observed company collected receivables from foreign customers in the amount of 186,494 thousand RSD due beyond one year. The predictive validity of the developed analytical model was evaluated by comparing the forecasted and actual receivables collection values.

For the forecast of receivables collection from domestic and foreign customers beyond one year, the accuracy of the model was validated within a deviation margin of +/– 3%. Similarly, the forecast accuracy for receivables due within one year from both domestic and foreign customers was confirmed within a deviation margin of +/– 5%. Therefore, these results support the conclusion that inputting current balance sheet data into the developed mathematical model enables reliable prediction of future balance sheet positions. This approach demonstrates its applicability across firms operating in the market.

The forecasting results regarding the collectability of customer receivables over short- and long-term horizons, obtained through the application of the absorbing Markov-chain model and the complementary Monte Carlo robustness analysis, can be compared with findings reported in the existing literature. The results provide a basis for discussing similarities and differences relative to previously developed forecasting models.

The mid-twentieth century witnessed the emergence of pioneering studies applying Markov chains to forecast the collectability of customer receivables. In their study, Cyert et al. (1962) developed an absorbing Markov chain for estimating expected losses arising from uncollectible receivables in a retail company. In contrast to managers' intuitive assessments, the authors proposed an approach based on transition probabilities between different receivables aging categories. The proposed model was based on the stability of the transition matrix and represented one of the earliest applications of Markov chains in receivables management. Corcoran (1978) developed receivables collection and cash inflow models through the application of Markov transition matrices. The study demonstrated that payment patterns serve as a basis for forecasting receivables collection. In addition, the empirical analysis was based on estimated transition probabilities between receivables states, with particular emphasis on forecasting cash inflows (Corcoran, 1978).

The application of Markov processes in finance expanded during the 1980s and 1990s through the modelling of receivables states and credit risk. These models employ homogeneous transition matrices to explain the probabilities of customers moving between different payment categories (short-term and long-term) or delinquency states. Such findings contributed to improving receivables collection forecasting, credit policy management, and corporate credit risk control. Kallberg and Saunders (1983) applied Markov chains to analyse the behaviour of revolving credit customers by modelling transitions between repayment and indebtedness states. The results indicate that repayment patterns and account characteristics predict future borrower behaviour. Building on these findings, subsequent studies incorporated borrower heterogeneity, improving the predictive performance of Markov models in credit risk assessment and receivables collection forecasting.

Over the last two decades, the methodological framework of this research area has expanded through the use of time-inhomogeneous transition matrices, the incorporation of macroeconomic factors, and simulation techniques. Some studies have employed Bayesian methods to estimate transition matrices and forecast transitions between repayment and delinquency states (Grimshaw & Alexander, 2011). Other studies have applied discrete Markov chains to quantify collection activities in consumer lending. The results indicate that collection activities influence transition probabilities between account states and shape borrower repayment behaviour (He et al., 2015). Among recent studies, Keyser et al. (2025) applied an absorbing discrete Markov chain with five transient and two absorbing states: collected and written-off receivables. Using balance sheet data on receivables, they constructed a transition probability matrix was constructed to estimate collection probabilities and the expected time to receivables resolution.

The findings of this research are consistent with earlier studies that recognize Markov processes as an effective approach to modelling receivables collection (Cyert et al., 1962; Kallberg & Saunders, 1983). It should be emphasized that earlier studies relied primarily on analytical estimates derived from transition matrices, whereas the present research complements the analytical Markov-chain model with a Monte Carlo robustness analysis to evaluate the variability of receivables collection outcomes under stochastic realizations of the selected transition probabilities. Therefore, this research builds upon studies that combine Markov-chain models for forecasting borrower behaviour patterns with simulation methods for assessing receivables collectability, as demonstrated by Baynes et al. (2023). However, unlike more complex credit risk assessment models, the proposed approach is adapted to the evaluation of corporate receivables collectability, with lower procedural complexity and fewer data requirements.

A multi-stage methodology integrating several analytical procedures is employed in this research. In the first stage, an absorbing Markov chain is used to estimate transition probabilities and receivables collectability. Subsequently, Monte Carlo simulation is applied as a complementary robustness analysis to construct confidence intervals for the simulated collection outcomes. One of the distinctive features of this research relates to the implementation of the empirical analysis, which is not based on a single corporate portfolio but on four distinct categories. The first dimension of segmentation classifies customers into domestic and foreign customers, while the second dimension classifies receivables into receivables due within one year and receivables due after more than one year. Such segmentation enables a more comprehensive analysis of the probability of receivables collection from domestic and foreign customers, as well as the time required for receivables to be collected, transition to another state, or ultimately to be classified as uncollectible receivables.

A limitation of this research relates to the insufficient transparency of corporate financial reporting. Specifically, corporate financial reports are publicly available only for a limited period, while balance sheets and income statements for certain fiscal years are not publicly available. Furthermore, some balance sheet items are omitted from the published financial statements, which significantly limits the accuracy and scope of the forecasting process. Future research should extend the application of the proposed model to a larger number of companies operating across different industries, as well as in countries with diverse business environments. Future studies may compare the business performance of firms that implement the proposed model with those that do not. Such an approach would provide valuable insights into the model's effectiveness in supporting efficient resource allocation and managerial decision-making.

6. Implications and conclusions

In this study, a model based on Markov chains was developed and applied to forecast the future value of corporate receivables. The proposed model represents an effective tool for managers by supporting business decision-making and reducing the risk associated with the future allocation of corporate resources. The findings of this research provide both theoretical contributions and practical implications.

The efficient allocation of a company's limited resources represents a fundamental function of economic systems and a core principle underlying the effective operation of individuals, firms, and societies. An inaccurate assessment of the future collectability of receivables may lead to high-risk investment decisions that are often based on managerial intuition rather than data-driven analysis. In this context, the theoretical and practical application of Markov processes is employed to forecast the collectability of receivables over both short- and long-term horizons. The analytical results are complemented by a Monte Carlo robustness analysis, which provides additional information on the variability of simulated collection outcomes. The modelling process confirms that Markov chains, as a class of stochastic processes, facilitate the prediction of variable values over both short and long-term horizons. The proposed approach does not require information on previous system states or historical company balance sheets. Instead, it relies on current financial statements to forecast future movements of the analysed variables with greater accuracy.

The findings indicate that receivables can be categorized into two distinct groups based on a qualitative assessment of financial statements. The first category comprises receivables from domestic customers, while the second includes receivables from foreign customers. By observing and monitoring the values of these balance sheet items, and through the development of forecasting models based on Markov processes complemented by Monte Carlo simulation, forecasts were generated for the collectability and non-collectability of receivables from both domestic and foreign customers over short-term and long-term horizons.

This research confirms the first hypothesis: that the application of the absorbing Markov-chain model, complemented by Monte Carlo robustness analysis, provides a reliable framework for predicting future business outcomes and supports more informed and effective managerial decision-making, notwithstanding the acknowledged limitations of the study. Decision-makers must take into account the volume of potentially uncollectible receivables when formulating short- and long-term strategies and making investment decisions.

The findings also confirm the second hypothesis, indicating that the application of the proposed modelling framework reduces risk in the decision-making process and enables a more efficient allocation of the company's limited resources. Ultimately, the absorbing Markov-chain model, complemented by Monte Carlo robustness analysis, enables accurate forecasting of receivables collectability, which contributes to risk reduction and enhances managerial decision-making, thereby supporting a more efficient allocation of company resources in the observed markets. The findings of this research are consistent with a fundamental principle of economics: understanding how individuals, companies, and societies make decisions and allocate scarce resources to improve their outcomes, strengthen their market position, and, more broadly, enhance overall social welfare.

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Poboljšanje potpore odlučivanju u alokaciji resursa primjenom Markovljevih lanaca za prognoziranje naplate potraživanja: Analiza robusnosti primjenom Monte Carlo simulacije

Đorđe Kotarac[1], *Zoran Popović*[2], *Goran Petković*[3]

Sažetak

Učinkovita alokacija resursa od strane pojedinaca, poduzeća i društva predstavlja jedno od središnjih pitanja ekonomske teorije i prakse. Postizanje ekonomskih ciljeva ovisi o sposobnosti raspodjele oskudnih resursa u uvjetima neizvjesnog poslovnog okruženja. Prognoziranje naplate potraživanja doprinosi učinkovitijoj i manje rizičnoj alokaciji resursa jer podupire donošenje odluka o budućoj raspodjeli imovine poduzeća. Ovo istraživanje razvija i primjenjuje okvir za prognoziranje temeljen na apsorbirajućem Markovljevom lancu, dopunjen analizom robusnosti putem Monte Carlo simulacije, kako bi se procijenile vjerojatnosti naplate potraživanja, očekivana vremena naplate, te projicirani novčani priljevi iz potraživanja u kratkom i dugom roku. Predloženi pristup omogućuje procjenu dinamike naplate i pruža dodatne informacije za financijsko planiranje i investicijske odluke. Rezultati ovog istraživanja pokazuju da pouzdano prognoziranje potraživanja može poboljšati učinkovitost alokacije imovine i smanjiti rizik pri donošenju investicijskih odluka, čime se podupire unaprjeđenje profitabilnosti poduzeća.

Ključne riječi: *prognoziranje naplate potraživanja, donošenje odluka, energetska industrija, Markovljevi lanci, Monte Carlo simulacija*

JEL klasifikacija: *C65, D25, E17*

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Appendix

Table A.1: Forecasting receivables collection intervals using Monte Carlo simulation

2021/2022	Collectability of receivables from domestic customers		
	Confidence interval	Receivables collection rate	Expected collection of receivables
Receivables from domestic customers up to one year	95%	66%	1,696,482
Receivables collection interval forecasts (domestic customers)			
Receivables from domestic customers over one year	95%	76%	1,640,722 - 1,644,764
2021/2022	Collectability of receivables from foreign customers		
	Confidence interval	Receivables collection rate	Expected collection of receivables
Receivables from foreign customers up to one year	95%	68%	181,543
Receivables collection interval forecasts (foreign customers)			
Receivables from foreign customers over one year	95%	72%	174,066 – 174,468

Note: The amounts reported in Table A.1 are expressed in thousand Serbian dinars (RSD)

Source: Authors' calculations

Table B.1: Forecast of receivables collectability and non-collectability using the Markov Chain model

	Collected receivables from domestic customers	Uncollected receivables from domestic customers	Collected receivables from foreign customers	Uncollected receivables from foreign customers
Receivables from domestic customers up to one year	350,223.50	272,991.50	0.00	0.00
Receivables from domestic customers over one year	347,888.00	112,740.00	0.00	0.00
Receivables from foreign customers up to one year	0.00	0.00	40,492.00	22,059.00
Receivables from foreign customers over one year	0.00	0.00	40,371.00	15,498.50
	Receivables from domestic customers up to one year	Receivables from domestic customers over one year	Receivables from foreign customers up to one year	Receivables from foreign customers over one year
Receivables from domestic customers up to one year	272,991.50	623,215.00	0.00	0.00
Receivables from domestic customers over one year	0.00	460,628.00	0.00	0.00
Receivables from foreign customers up to one year	0.00	0.00	22,059.00	62,551.00
Receivables from foreign customers over one year	0.00	0.00	0.00	55,869.00

Note: The amounts reported in Table B.1 are expressed in thousand Serbian dinars (RSD)

Source: Authors' calculations

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Dynamic Optimisation and Scenario Analysis of the Romanian Public Pension System*

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Abstract

The literature on the sustainability of publicly financed pension systems predominantly focuses on long-term demographic and fiscal projections, while considerably less attention is devoted to the explicit identification of optimal policy solutions that jointly minimise economic and social costs. This paper addresses this gap by embedding pension policy decision making in a dynamic optimisation framework based on the Bellman equation, enabling the identification of economically and socially optimal policy paths. The study examines whether the long-term sustainability of the Romanian public pension system can be enhanced through optimally timed policy interventions while limiting economic and social burdens. The proposed model integrates demographic dynamics, labour market behaviour, and fiscal constraints within a unified analytical framework. It optimises seven key decision variables, including the retirement age of women and men, the social security contribution rate, the early retirement rate, the proportion of active pensioners, and the employment rate. Scenario simulations for the period 2024-2036 demonstrate that maintaining the current retirement age cannot be achieved optimally through contribution-rate adjustments alone. The results emphasise the crucial role of extending pensioners' labour-market participation, which substantially reduces fiscal pressure and enhances long-term system sustainability. The methodology is adaptable to other national pension systems and supports integrated pension-policy design.

Keywords: *public pension systems, dynamic scenario analysis, optimisation, Romania, pension system policies*

JEL classification: *C53, H55, H62, I38*

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1. Introduction

The sustainability of pension systems is a multidimensional challenge (Balteș et al., 2018; Litterman & Sharpe, 2014), and this complexity makes short-term thinking and decision making inadequate (Bărbulescu, 2013). A multisectoral approach is required to achieve sustainability (Simonovits, 2003), which may also help improve the social distrust associated with public pension systems in Central and Eastern Europe (Chłoń-Domińczak, 2018). Consequently, forecasting tools and dynamic models are necessary to understand the system's dynamics and to simulate the long-term impact of decisions, thereby providing a rational basis for debate on pension reform (Disney, 2001) and reducing the pressure of changing demographic structures on public finances (Fougère & Mérette, 1999; Meier & Werding, 2010).

Literature on the sustainability of public pension systems predominantly relies on long-term demographic and fiscal projections and their expected consequences, while devoting considerably less attention to analyses that explicitly identify optimal policy solutions capable of simultaneously minimising economic and social costs. As a result, and as argued by Kahneman et al. (2021), decision making in noisy and uncertain environments often fails to minimise the costs of decisions. This study seeks to address this research gap by explicitly focusing on the optimisation of pension policy decision-making processes. The central research question is whether the long-term sustainability of the Romanian public pension system can be improved through optimally timed and jointly coordinated policy interventions, given a specific pension policy priority decision, while minimising economic and social adjustment costs. The aim is to identify decision alternatives that effectively support cost-efficient and socially acceptable policy choices. Accordingly, the aim of this paper is to develop and apply a Bellman-equation-based dynamic optimisation model that integrates social, economic, and legal constraints within a unified analytical framework. By jointly optimising seven key decision variables, namely the statutory retirement ages of women and men, the social security contribution rate, the national average gross wage, the early retirement rate, the proportion of active pensioners, and the employment rate, the model determines adjustment paths that are optimal from both economic and social perspectives. Scenario simulations for the period 2024-2036 aim to evaluate alternative policy strategies and to identify combinations of instruments that mitigate fiscal pressure and contribute to the long-term sustainability of the pension system. Although the empirical application focuses on Romania, the proposed methodology and optimisation framework are adaptable to pension systems in other countries, particularly in regions facing similar demographic and economic challenges. The implementation is carried out in the MATLAB programming environment.

From a system dynamics perspective, the analysis of the pension system is divided into three levels. Level 1 involves the statistical analysis of each parameter separately using relevant statistical indicators. Level 2 constructs a dynamic model to examine how the pension system changes when multiple parameters are varied simultaneously. This level determines the optimal functioning of the system based on a priority order formulated by decision makers. The paper focuses on this level by setting up scenarios for decision makers, studying the interactions among the parameters that form the system, and incorporating a penalty function and dynamic modelling to achieve an optimal outcome. These scenarios provide possible outcomes for decisions, model and predict the impact of different factors, and assist decision makers in selecting the best policy direction to ensure the sustainability of the pension system and the well-being of pensioners. Level 3 transforms the dynamic system into an adaptive system to identify its internal equilibrium, representing a further development of the current research.

This paper develops a dynamic model of the pension system based on the Bellman equation (Hillier & Lieberman, 2021), an approach that has not yet been encountered in the existing literature. The complexity of pension systems necessitates a shift from simpler static models to dynamic modelling, which not only considers the effect of changing a single parameter on the system's equilibrium, but also captures the interdependent shifts of parameters and the optimal timing for corresponding decisions to reach the optimal state of the objective function. The dynamic programming model facilitates the implementation of a country's pension model, with changes being easily integrated due to the model's adaptive nature.

Studies on the sustainability of the Romanian pension system have examined three major demographic challenges: population decline, population ageing (including declining birth rates), and migration trends expected to persist over the next three decades (Stancu et al., 2019). The pension system can be understood as a mapping of the demographic age structure (Koettl et al., 2014). Although Romania currently has a younger population than most European countries, creating a potential for a dynamic labour market (Stancu et al., 2019), fostering economic growth is not being exploited effectively. Over the next 50 years, however, Romania is projected to become one of the oldest populations in Europe, with severe social and economic impacts (Dobre et al., 2012). For instance, while the dependency ratio was 0.85 pensioners per worker in 2010, it is expected to rise to 1.5 pensioners per worker by 2060 (Dobre et al., 2012), indicating that population ageing negatively affects multiple dimensions of social and economic life (Eleftherios et al., 2019).

The Ministry of Finance has estimated that the pension system's budget deficit could reach 87.9 billion lei by 2050 (Stancu et al., 2019), requiring state-budget transfers that would have lasting impacts on the financing of future investments. Projections suggest that even an increase in the employment rate alone will not resolve the sustainability issue in the long run (Pânzaru, 2015). Although reducing migration is often proposed as a solution to the labour market imbalance, its impact on ensuring the sustainability of the pension system remains hypothetical (Pânzaru, 2015).

Regular projections of future pension liabilities are currently based on reasonable assumptions about macroeconomic and demographic trends, which can be used to simulate the contribution rates required to achieve the most favourable financial outcomes (Disney, 2001). The eighth edition of the European Commission's *The Ageing Report*, published in 2024, provides long-term projections of the budgetary impact of population ageing in Romania for the period 2022–2070 (European Commission, 2024).

The study tests the following hypotheses:

> H1: *In the Romanian public pension system in force in 2024, preserving the current retirement age as a primary policy objective cannot be achieved optimally solely through adjustments to the social security contribution rate.*
>
> H2: *The activation of the retired population in the Romanian labour market is a key determinant in attaining optimal outcomes under the analysed policy scenarios.*
>
> H3: *The magnitude of the real pension system deficit in the Romanian public pension system in 2024 can be reduced through appropriate policy interventions compared with the no-intervention baseline, as indicated by the optimal policy scenarios.*

The paper begins with a review of the relevant literature, outlining the theoretical background of Bellman's dynamic programming, followed by a detailed methodological section and the presentation of optimal scenarios. After that, the results are discussed, and the paper concludes with a summary and suggestions for future research.

2. Literature review

According to UN projections, the proportion of the world's population aged 60 and over, which was 8% in 1950 and 11% in 2009, is expected to reach 22% by 2050 (United Nations, 2010). Hyndman et al. (2021) attribute this trend to three primary factors: advancements in healthcare systems that have significantly increased life expectancy, the ageing of the baby-boomer generation born in the mid-20th century, and a marked decline in birth rates over the past three decades (Fehr et al., 2008).

2.1. Demographic trends and economic challenges in public pension systems

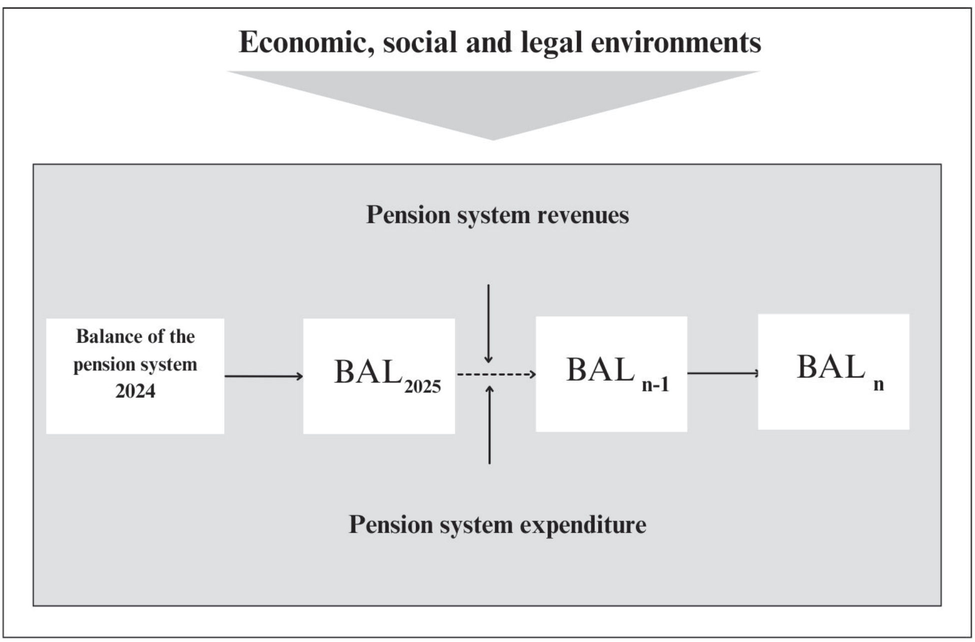
Hyndman et al. (2021) employ a stochastic population-projection method to analyse Australia's pension system. Their study is based on interrelated functional data models of mortality, fertility, and net migration, which together forecast the future structure of the population. This approach combines the functional demographic models of Hyndman and Ullah (2007) with the general stochastic population-projection framework of Hyndman et al. (2013) and utilises the age-structure projections from Hyndman and Booth (2008). Population ageing is quantified using the old-age dependency ratio. Similarly, Bazzana (2020) examines the effect of altering the retirement age on the sustainability of PAYG pension systems and the evolution of public debt. This economic perspective builds on the findings by Galasso (2008) and Godínez-Olivares et al. (2016), who show that increasing the retirement age can reduce pension system deficits, although Magnani (2011) and Miyazaki (2014) argue that this measure alone does not provide a long-term solution. Boado-Penas et al. (2020) find that linking the retirement age to life expectancy in the decision-making process, which is an approach adopted by many countries, can be effective, albeit as a parametric reform that must be combined with other measures to fully address the issue.

Bazzana (2020) concludes that extending the retirement age, and thus the working age, decreases the proportion of retirees, reduces pension expenditures, and lowers both the system deficit and the debt stock. This policy increases the number of active workers, yielding positive effects on overall output and tax revenue, though it may also create social tensions. Comparable outcomes are observed when the government opts to reduce pension contributions (Bazzana, 2020), a proposal also discussed by Boado-Penas et al. (2020). However, such an approach could lead to serious social challenges by impoverishing the elderly and widening the economic gap between active and inactive populations. A third option for deficit reduction could involve higher taxation on labour income (Bazzana, 2020).

The determinants of the pension system can be divided into economic, social, and legal environments, as illustrated in Figure 1. A lack of coherence among these factors leads to sustainability issues (Guardiancich, 2012), as the income, expenditure, and overall balance of the pension system depend on parameters from all three domains. This three-dimensional classification is applied in the simulation model of the Spanish pay-as-you-go (PAYG) pension system developed by Villanueva-García et al. (2025), who project the future evolution of the system up to 2060. A similar analytical framework is employed in the methodological approaches adopted by the OECD (2023) and the European Commission (2024).

In this paper, the social dimension corresponds to the demographic component defined by Villanueva-García et al. (2025). The most important determinants within this component include trends in the number of births and net migration flows, as well as mortality patterns and changes in life expectancy. The economic dimension captures labour market and macroeconomic processes, including employment and unemployment rates, the overall economic environment, productivity developments, and changes in the national average wage level. These factors directly influence the evolution of social security contribution revenues and, consequently, the financial balance of the pension system. The third dimension refers to the institutional and legal framework governing the operation of the pension system. This includes the statutory retirement age, the regulation of pension benefits and contribution rates, and the eligibility conditions for pension entitlements. This dimension plays a crucial role in shaping both the long-term sustainability of the system and the adequacy of pension benefits. The seven decision parameters analysed in this study – the statutory retirement age for women and men, the social security contribution rate, the national average gross wage, the early retirement rate, the proportion of active pensioners, and the employment rate – collectively span these three dimensions. The dimensions are interdependent, as are the seven decision parameters themselves, reflecting the complex and interconnected nature of demographic, economic, and institutional mechanisms within the PAYG pension system. In the context of pension system reforms, it is essential to consider transitional costs at both economic and social welfare levels, in addition to demographic and fiscal constraints, as these costs may be substantial relative to the long-run policy objectives (Heer et al., 2023). This consideration applies across different pension policy goals, and the model presented in this paper explicitly allows for the optimisation of the entire adjustment path rather than focusing solely on the final steady-state outcome.

Figure 1: Diagram of the pension system



Source: Author’s illustration

The basic projection model for the Romanian pension system is based on the World Bank's Pension Reform Options Simulation Toolkit (PROST) (European Commission, 2024). This model primarily assists in designing objective pension policies, although it does not generate optimal scenarios. Input data and forecasts for the model are provided by Eurostat.

2.2. Bellman equation, dynamic programming

In the modelling of issues related to pension systems, dynamic optimisation is a widely used approach. Fehr and Fröhlich (2023) formulate individual decision making within a recursive optimisation framework in a general equilibrium life-cycle model, where households choose among continued labour market participation, standard retirement, and the uptake of disability pensions. The application of the Bellman principle enables the numerical derivation of optimal decision rules under alternative institutional configurations. Their results indicate that increasing the statutory retirement age alone may induce a shift towards disability retirement, highlighting the need for coordinated optimisation of old-age and disability pension schemes.

Research on the optimal timing of statutory retirement age increases in a dynamic framework examines how retirement age reforms can be scheduled in a way that distributes actuarial losses across generations in an equitable manner, while also assessing the role of demographic structure and benefit formulae. Findings indicate that the welfare effects of raising the retirement age depend critically on the adjustment path and that dynamically optimised, gradual reforms are associated with substantially lower transitional costs than one-off, discrete policy interventions (Zhang & Zhu, 2024).

Ji et al. (2022) analyse the long-term operation of pension systems within a stochastic optimisation framework, applying a model that combines multistage stochastic programming with dynamic stochastic control. Their approach explicitly addresses demographic decline and ageing-related financing challenges, while allowing short- and medium-term uncertainties to be incorporated into the optimal management of public pension systems.

Short-term effects of increases in the statutory retirement age may exhibit substantial heterogeneity, which points to the need for a dynamic and intertemporally optimised approach to pension reforms (Nivalainen & Ilmakunnas, 2025).

Godínez-Olivares et al. (2016) develop a dynamic optimisation framework for a sustainable PAYG pension system, in which automatic balancing mechanisms determine the optimal time paths of the contribution rate, statutory retirement age, and pension indexation. Their results indicate that the sustainability of PAYG pension systems can be substantially improved through the jointly and dynamically optimised adjustment of multiple policy parameters, ensuring financial balance under demographic and economic fluctuations with lower volatility and reduced adjustment costs, while requiring minimal discretionary legislative intervention.

The Bellman equation provides the value of a decision problem at a given point in time by equating it to the sum of the immediate decision profit and the value of the subsequent decision problems resulting from that initial decision (Kirk, 1970). Its application originated in engineering control theory and applied mathematics, where research questions are frequently formulated as Multi-Stage Optimisation Problems (MSOPs) (Jones & Peet, 2021; Liu et al., 2019; Zeng & Wang, 2018). Over time, the Bellman equation has become an important tool in economics (Merton, 1973). Typically, the term *Bellman equation* is used to refer to a discrete-time dynamic-programming equation associated with an optimisation problem.

The characteristics of a dynamic programming problem, both in general (based on Hillier & Lieberman, 2021) and in relation to a pension scheme, can be outlined as follows.

Decomposability and interrelated decisions: The problem under consideration can be segmented into distinct sections, each requiring a strategic decision. In the case of a pension system, the state is represented by the pension system balance, which is directly influenced by strategic decisions made on an annual basis. Each year, therefore, constitutes a stage during which policymakers can influence the system's balance through their decisions.

Association of stages with states: Each stage is associated with a state that represents the expected conditions at that point in time. In the context of the pension system, this involves specifying the intervals within which relevant variables may fluctuate during a given year.

State transitions induced by decisions: A decision taken at one stage results in a new state for that stage, from which the next stage commences. In the pension scheme, a strategic decision made in one year alters the system's variables, thereby establishing a new state on which the decisions of the subsequent year are based.

Optimisation across multiple stages: The overall objective is to determine the optimal strategies for the problem by ensuring that the most effective decision is made at each stage. For the pension system, this means that each year must meet the system's target in an optimal manner by appropriately adjusting the parameters. Importantly, the focus is not solely on the final year; rather, the entire process is critical for achieving the desired outcome.

Independence and the Markov property: Decisions made in the current phase are independent from previous decisions; however, the current state contains all the necessary information (i.e., previous decisions and their outcomes) that is essential for determining the optimal subsequent steps. This characteristic, known as the Markov property or the optimality principle, implies that the optimal decision for the pension system in any given year depends solely on the current state.

Backward solution process: The solution process is initiated in a backward manner, beginning with the determination of the optimal strategy for the final stage. For the last n years of the process, the decision that optimises the objective function is determined first, followed by the optimal decision for year n–1, and so forth.

Recursive determination of the optimal strategy: Within a recursive framework, the optimal strategy at stage n is determined under the assumption that the optimal strategy for stage n+1 is already known.

Backward movement through states: Based on the recursive relationship, the solution process moves backwards from state to state, selecting the optimal strategy for each state until the initial state is reached.

3. Methodology and empirical data

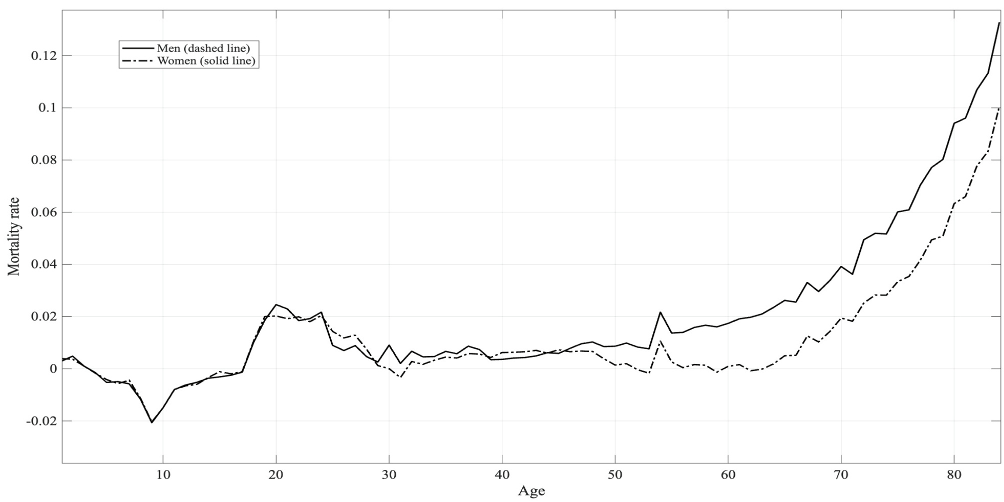
A dynamic pension model was developed to evaluate policy trade-offs and assess long-term fiscal and social sustainability. The model optimally adjusts seven key policy variables on an annual basis: retirement age for women (arw_n), retirement age for men (arm_n), contribution level (T_n), gross national average wage ($\bar{S}_n$), early retirement rate (e_n), the proportion of active pensioners (k_n), and the employment rate (u_n), based on the decision-maker's priorities. Each variable is optimised subject to a set of constraints derived from legislative and economic considerations, while additional parameters are estimated using secondary data from Eurostat and INSSE.

The information technology algorithm required for the implementation was previously presented in an integrated form together with the associated methodological framework (Lőrincz & Makó, 2025). As noted in that study, a subsequent publication was intended to address the application of the model. Accordingly, the present article applies the algorithm explicitly as an optimisation tool and examines its economic applicability through the presentation and interpretation of the scenarios generated during the implementation.

3.1. Population dynamics, empirical data

Population indicators constitute the fundamental input to the model, as they determine the demographic structure essential for pension financing (Simonovits, 2002). For the dynamic model under consideration, it was necessary to estimate the annual population numbers for each age group and sex. To this end, data were obtained from the national statistics office (INSSE) for the period 2010-2023. The change in population by age (transition-loss rate) is illustrated in Figure 2. This information is subsequently employed to project the future evolution of the population, thereby establishing a deterministic model. In the model, the grey-shaded plots represent the transition-loss rates for various age groups (a), sexes (g, where w indicates women and m men) and years (n) as part of the $MR_{a,n,g}$ distribution. The bold black lines, dashed for men and solid for women, represent the averaged transition-loss values for men ($AMR_{a,n,m}$) and for women ($AMR_{a,n,w}$). The figure shows a local maximum point after the age of 20, reflecting higher migration among individuals in this age group. Thus, the model accounts for migration in addition to mortality in the population projections by treating migration-induced cohort changes as part of an aggregate transition-loss parameter, which captures net population transition loss rather than biological mortality.

Figure 2: Age-specific population transition-loss rates by sex



Source: Author's illustration, based on INSSE population data for the period 2010-2023

Population data are organised in two gender-specific age-by-year population matrices. The matrix $Pop_m \in \mathbb{R}^{86\times14}$ represents the male population, while $Pop_w \in \mathbb{R}^{86\times14}$ represents the female population. In both matrices, rows correspond to single-year age cohorts (from age 0 to 84, with the last row representing the open-ended 85+ age group), and columns correspond to calendar years covering the period 2010–2023.

$$Pop_g = \begin{pmatrix} Pop_{0,2010,g} & \cdots & Pop_{0,2023,g} \\ \vdots & \ddots & \vdots \\ Pop_{85+,2010,g} & \cdots & Pop_{85+,2023,g} \end{pmatrix} \in R^{86*14}, g \in \{m, w\} \tag{1}$$

The notation $Pop_{a,n,g}$ denotes a scalar element of the corresponding population matrix, representing the number of individuals of age *a* and gender *g* in year *n*.

Based on these cohort-level population values the transition-loss rate $MR_{a,n,g}$, measuring the relative change in cohort size from year *n* to year *n* + 1 due to mortality and migration effects, is defined for each cohort as follows:

$$MR_{a,n,g} = \frac{(Pop_{a,n,g} - Pop_{a+1,n+1,g})}{Pop_{a,n,g}} \tag{2}$$

For the period 2010-2023, the transition loss rate $MR_{a,n,g}$ is computed and averaged to obtain the average transition-loss rate $AMR_{a,g}$:

$$AMR_{a,g} = \frac{1}{14} \sum_{n=2010}^{2023} MR_{a,n,g} \tag{3}$$

Future population evolution is then forecast as:

$$Pop_{a+1,n+1,g} = Pop_{a,n,g} * (1 - AMR_{a,g}) \tag{4}$$

Within the model, the total population for a given year *n* is partitioned into three segments: the underage ($YP_{n,g}$), the working-age ($UP_{n,g}$), and the elderly ($OP_{n,g}$). These are defined as follows:

$$Pop_{n,g} = YP_{n,g} + UP_{n,g} + OP_{n,g} \tag{5}$$

$$YP_{n,g} = \sum_{a=0}^{18} Pop_{a,n,g} \tag{6}$$

$$UP_{n,g} = \sum_{a=18}^{ar_n} Pop_{a,n,g} \tag{7}$$

$$OP_{n,g} = \sum_{a=arm_n}^{a\_max_{n,m}} Pop_{a,n,m} + \sum_{a=arw_n}^{a\_max_{n,w}} Pop_{a,n,w} \tag{8}$$

Retirement age constraints are defined as $65 \leq \mathrm{arm}_n \leq 70$ for men and $63 \leq arw_n \leq 68$ for women. The max_n is the highest age in year *n*. These demographic projections are critical for understanding the labour force and pensioner segments, which, in turn, affect the financial dynamics of the pension system.

3.2. Financial balance and pension system mechanics

The model assumes a mandatory PAYG pension system financed primarily through social-security contributions. In cases where contributions do not cover pension expenditures, the deficit is financed from the state budget (Vallasek, 2015). The pension-system balance BAL_n for year n is the difference between its revenues REV_n and expenditures EXP_n:

$$BAL_n = REV_n - EXP_n \tag{9}$$

where revenue (REV_n) is calculated as:

$$REV_n = T_n{}^*\bar{S}_n{}^*C_n{}^*12 \tag{10}$$

In this expression, T_n denotes the contribution rate (with T_1 = 20.25% and a constraint $15\% \leq T_n \leq 30\%$), and $\bar{S}_n$ represents the gross national average wage (with $\bar{S}_1$ = 7,567 lei and a constraint $5{,}000 \leq \bar{S}_n \leq 12{,}000$). The number of employed individuals (C_n) is determined by:

$$C_n = LF_n{}^*u_n{}^*k_n{}^*OP_n \tag{11}$$

In this formula, u_n denotes the employment rate (with an initial value of $u_1 = 64\%$ and a constraint $60\% \leq u_n \leq 68\%$) and k_n the percentage of active pensioners (constraint $0\% \leq k_n \leq 30\%$); k_n is calculated on the basis of the optimised parameters determined by the model. $\wp_n$ denotes the size of the working-age population, (in the Romanian case, $\wp_1$ amounts to 8,364,000 individuals). The labour force (LF_n) is then calculated as:

$$LF_n = \wp_n{}^*(1 - ds_n{}^*er_n) + NM_n \tag{12}$$

In this expression, ds_n is the disability rate based on Eurostat data, er_n represents the early retirement rate (with $0\% \leq er_n \leq 5\%$) and NM_n refers to the net working-age migration. Changes in T_n and $\bar{S}_n$ affect the employment rate and net migration via elasticity factors ($eu_{\bar{S}_n}$ the coefficient of elasticity of employment rate with respect to gross wage, euT_n the coefficient of elasticity of the employment rate with respect to the contribution level, $em_{\bar{S}_n}$ coefficient of elasticity of net migration with respect to gross wage, emT_n the coefficient of elasticity of the net migration with respect to the contribution level)

$$\frac{u_n - u_{n-1}}{u_{n-1}} = \left(\frac{\bar{S}_n - \bar{S}_{n-1}}{\bar{S}_{n-1}}{}^*eu_{\bar{S}_n} + \frac{T_n - T_{n-1}}{T_{n-1}}{}^*eu_{T_n}\right) \tag{13}$$

$$\frac{NM_n - NM_{n-1}}{NM_{n-1}} = \left(\frac{\bar{S}_n - \bar{S}_{n-1}}{\bar{S}_{n-1}} * em_{\bar{S}_n} + \frac{T_n - T_{n-1}}{T_{n-1}} * em_{T_n}\right) \tag{14}$$

Expenditures (EXP_n) are computed based on the number of pensioners (P_n) and the national average pension ($\overline{PP}_n$) and old-age retirement rate (rr_n):

$$EXP_n = P_n * \overline{PP}_n * 12 \tag{15}$$

where the number of pensioners (P_n) is calculated as the number of elderly individuals (OP_n) multiplied by the proportion of the population eligible for pension benefits (rr_n):

$$P_n = OP_n * rr_n \tag{16}$$

Pension adjustments reflect the legal provisions established by Law 263/2010. Until 2030, pension increases account for both inflation and a diminishing proportion of real wage growth, with a transition to inflation-only adjustments thereafter. This mechanism aims to protect the beneficiaries of the system from impoverishment caused by the erosion of purchasing power due to inflation (Simonovits, 2016).

The Romanian Pension Law 360/2023, in force since 1 January 2024 (Romanian Parliament, 2023), defines annual pension indexation as the sum of full inflation compensation and 50% of real wage growth. In practice, however, the application of this rule remains is subject to fiscal and implementation constraints, and the legislation allows for its partial or temporary suspension. Given the current budgetary position of Romanian public finances, as well as the increasingly binding demographic and fiscal challenges affecting the pension system, the indexation mechanism applied in the analysis is restricted, from 2030 onwards, to the preservation of the real value of pensions only. This approach aligns with recent policy practice and enables a conservative and distortion-free assessment of pension system sustainability in an uncertain macroeconomic environment. Furthermore, the analysis explicitly aims to preserve at least the 2024 real-level benchmark across all decision parameters, thereby preventing real deterioration, which is also consistent with the determination of the pension contribution rate.

$$\overline{PP_{n-1}} = \begin{cases} \overline{PP_{n-1}} * \left[i_n + 1\left(\left(\frac{S_n}{S_{n-1}} - 1\right) * r\right)\right], & if \quad n \le 2030, \\ \overline{PP}_n = \overline{PP}_{n-1} * [i_n + 1], & if \quad n > 2030 \end{cases} \tag{17}$$

$$If\ n \in [2024{,}2030],\ r = 0.3 - \left(0.05 * (n - 2024)\right) \tag{18}$$

3.3. Optimisation framework

The core of the model is an optimisation problem solved using dynamic programming. The algorithm proceeds backward from the final period n to period 1, identifying the optimal sequence of decisions for the variables arw_n, arm_n, T_n, $\overline{S}_n$, e_n, k_n and u_n that minimise a weighted penalty function. The penalty function quantifies deviations from the baseline (2024) values of these normalized variables, thereby reflecting the extent to which social welfare and economic sustainability are impaired relative to the 2024 situation. A decision matrix A is defined, where each row represents a year, and the columns contain the decision variables weighted by parameters W, M, B, C, D, E, and G. The sum of these weight parameters equals one. The weights parameters in the penalty function model the views of the decision makers. Magnitudes of the weights indicate the order of importance of these decision parameters. The normalization is performed with respect to the 2024 baseline (the first row of the matrix is set to zero):

$$A = \begin{array}{c} \\ A_1 \\ \vdots \\ An \end{array} \begin{array}{c} \begin{array}{ccccccc} M & W & B & C & D & E & G \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \frac{arm_n - arm_1}{arm_1} & \frac{arw_n - arw_1}{arw_1} & \frac{T_n - T_1}{T_1} & \frac{\overline{S}_n - \overline{S}_1}{\overline{S}_1} & \frac{BAL_n - BAL_1}{BAL_1} & \frac{er_n - er_1}{er_1} & \frac{u_n - u_1}{u_1} \end{bmatrix} \end{array} \quad (19)$$

The welfare (penalty) function for year n is defined as:

$$F_n = M\frac{arm_n - arm_1}{arm_1} + W\frac{arw_n - arw_1}{arw_1} + B\frac{T_n - T_1}{T_1} + C\frac{\overline{S}_n - \overline{S}_1}{\overline{S}_1} + D\frac{BAL_n - BAL_1}{BAL_1} + \\ + E\frac{er_n - er_1}{er_1} + G\frac{u_n - u_1}{u_1} \quad (20)$$

The optimal dynamics are obtained by solving the Bellman equation:

$$F_{n-1}^{*}\left(arm_{n-1}^{*}, arw_{n-1}^{*}, T_{n-1}^{*}, \overline{S}_{n-1}^{*}, Pop_{n-1}^{*}, er_{n-1}^{*}, k_{n-1}^{*}, u_{n-1}^{*}\right) \\ = F_n\left(arm_n, arw_n, T_n, \overline{S}_n, Pop_n, er_n, k_n, u_n\right) + \\ F_n^{*}\left(arm_n^{*}, arw_n^{*}, T_n^{*}, \overline{S}_n^{*}, Pop_n^{*}, er_n^{*}, k_n^{*}, u_n^{*}\right) \quad (21)$$

An asterisk is used to mark values that are optimal over the remaining time horizon starting from period n. Accordingly, F_n^{*} denotes the lowest attainable value of the penalty function evaluated over all subsequent stages until the terminal period. The framework is subject to an extensive system of constraints, ensuring that the derived policy paths are both feasible and grounded in realistic institutional conditions.

$$\begin{cases} f(1) & 65 \leq arm_n \leq 70 \\ f(2) & 63 \leq arw_n \leq 70 \\ f(3) & 15\% \leq T_n \leq 30\% \\ f(4) & 5{,}000 \leq \overline{S}_n \leq 12{,}000 \\ f(5) & 0 \leq BAL_n \leq 0.5 * BAL_1 \\ f(6) & 0 \leq er_n \leq 3\% \\ f(7) & 60\% \leq u_n \leq 68\% \end{cases} \tag{22}$$

The goal is to solve the following optimisation problem:

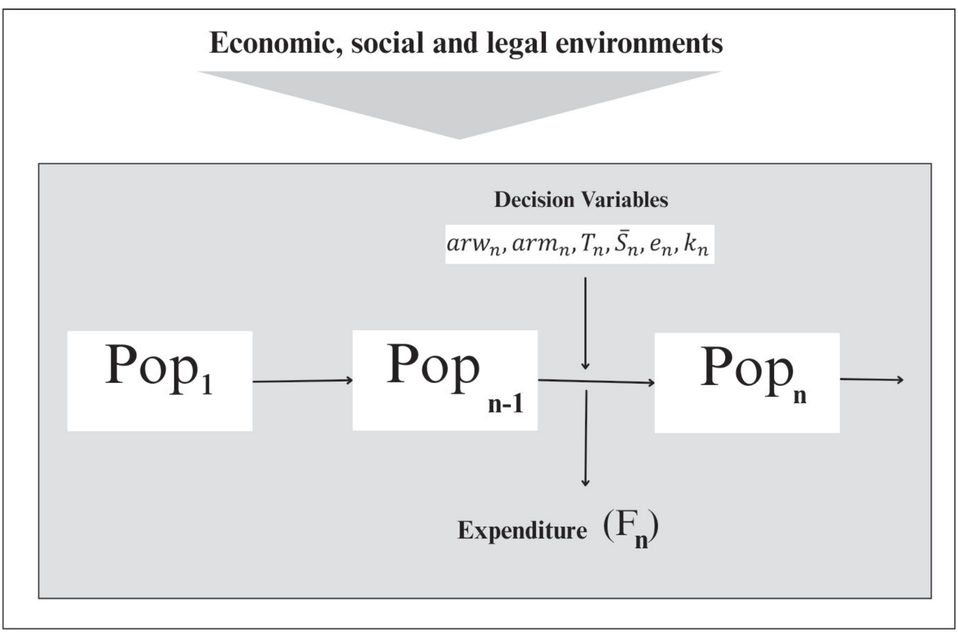
$$\begin{cases} F_1(arm_1, arw_{1,} T_{1,} \bar{S}_{1,} Pop_{1,} er_{1,} u_1) \to min \\ BAL_n \leq 0.5 * BAL_1 \end{cases} \tag{23}$$

State transitions are governed by:

$$\begin{cases} F_n = F_n(arm_n, arw_n, T_n, \overline{S}_n, Pop_n, er_n, k_n, u_n) \\ BAL_n = BAL_n(arm_n, arw_n, T_n, \overline{S}_n, Pop_n, er_n, k_n, u_n) \end{cases} \tag{24}$$

Figure 3 provides a graphical summary of the model structure.

Figure 3: Dynamic model of the pension system



Source: Author's illustration

The penalty function balances living standards and financial sustainability by penalizing deviations from the 2024 baseline in key areas such as retirement age, contribution levels, wage growth, pension system balance, early retirement rate, and employment rate. The assigned weights reflect the priorities of decision-makers: for instance, ensuring that retirement ages evolve in line with life expectancy trends while avoiding excessive pressure on the active workforce. Similarly, restrictions on wage growth and careful monitoring of pension deficits are essential to maintain fiscal stability.

In analysing the pension-policy options considered in the scenarios, several research questions emerge as central. What are the social and economic costs associated with maintaining the current retirement age? Is this scenario realistically achievable? Is it feasible, within the optimised scenario, to simultaneously maintain both the current retirement age and a stable contribution rate? To what extent can the pension system deficit be reduced if deficit reduction is treated as the primary objective? What optimal scenario is reached when the decision-maker assigns equal importance to all weight parameters? Finally, what interventions are necessary to implement these scenarios?

4. Results and discussion

The MATLAB programming environment was employed to implement the dynamic pension model. Initially, the evolution of the female and male populations was projected based on population data spanning from 2010 to 2023. On an annual basis, the model disaggregates the population into the underage, working age, and elderly segments according to the designated retirement age. The program begins its computation in the final year and proceeds backwards to 2024. During this backward induction, several potential trajectories leading to the 2024 state are determined based on the relations outlined in equation (23), while strictly adhering to the imposed constraints. Subsequently, in accordance with Bellman's equation (referenced as equation 21), the algorithm selects the optimal solution that minimises the penalty function using the currently assigned priority weights. With respect to the system of equations, Equations (1)-(8) constitute the Demographic Module, which provides the demographic forecasting framework of the model. Equations (9)-(18) form the Financial Balance and Pension System Dynamics module, while Equations (19)-(24) define the Optimisation Framework. Importantly, all three modules are jointly required to generate the simulation results: the outputs of the Demographic and Financial modules serve as essential inputs to the Optimisation Framework, and the combined interaction of all three modules underlies the scenario analyses and the resulting figures presented in the subsequent sections. The detailed integration of these modules with the underlying computational and programming framework has been published in an information-technology-focused scientific journal (Lőrincz & Makó, 2025).

Following the determination of the optimal solution, the resulting trajectory is illustrated through nine figures, each illustrating a key variable of the pension system. The x-axis represents calendar years from the baseline year 2024 to 2036, while the y-axis displays the policy-relevant variables central to the functioning of the pension system. The first two figures show the statutory retirement age for men and women, respectively, expressed in years. The third figure presents the social security contribution rate, expressed as a percentage. The fourth figure displays the national average gross wage, expressed in Romanian lei and measured in real terms relative to the 2024 baseline. The fifth figure illustrates population-related indicators, including the number of employed individuals and the number of pensioners. The sixth figure reports the magnitude of the pension system deficit, expressed in real terms relative to the year 2024. The seventh figure displays the early retirement rate, expressed as a percentage. The eighth figure shows the proportion of pensioners who remain active in the labour market, also expressed as a percentage, while the ninth figure presents the employment rate, expressed in percentage terms. In all figures, black dots indicate the range of feasible solutions, whereas solid black circles denote the optimal solutions attained in the corresponding years.

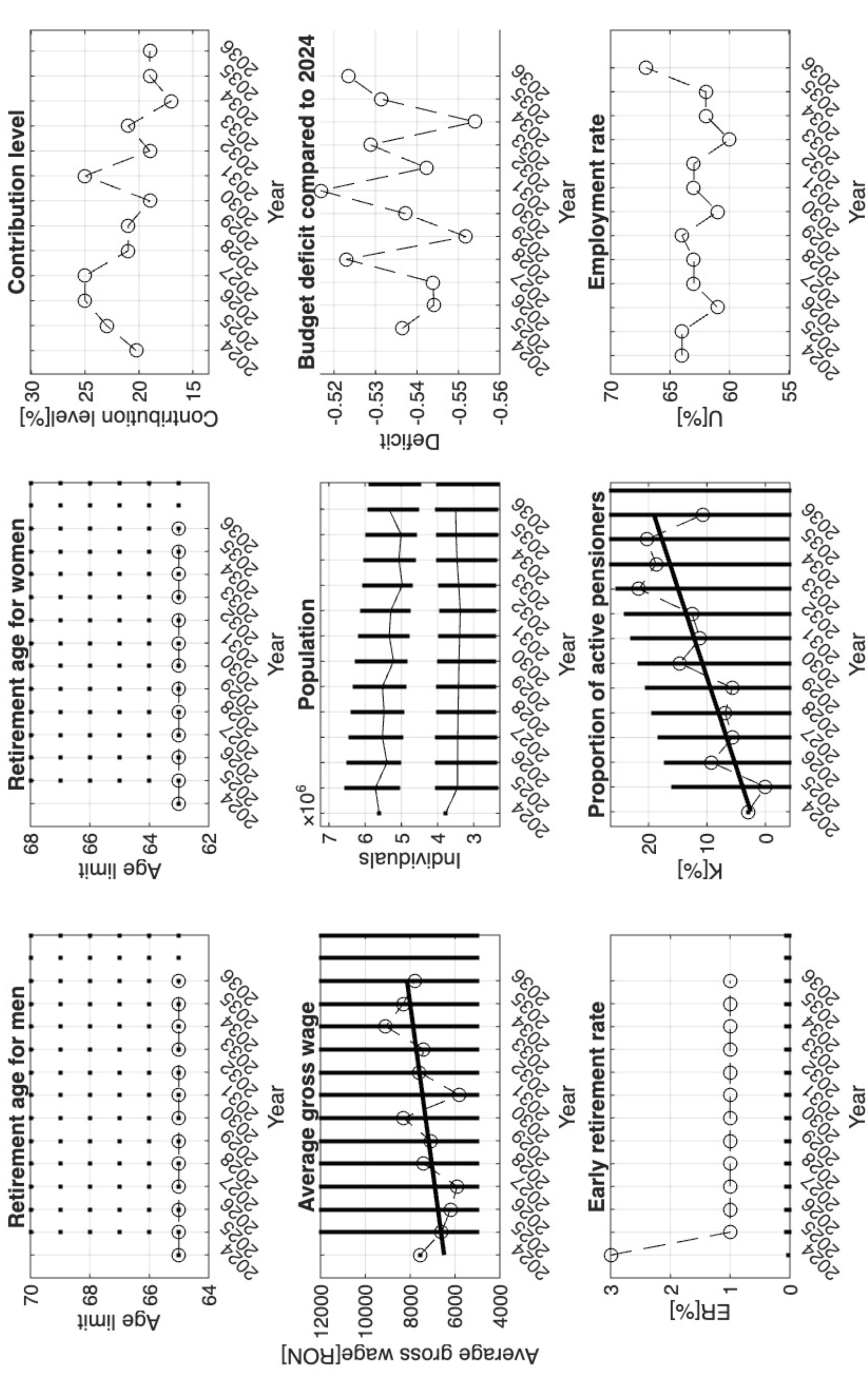
In terms of fiscal implications, public-pension expenditures accounted for 8.5% of GDP in 2022, with projections indicating an increase to 10.4% by 2030, as reported by the European Commission (2024). This significant escalation in costs underscores the urgency of addressing the financial challenges facing the pension system. To mitigate this critical period of fiscal strain, timely policy decisions are essential, and the various scenarios generated by the model offer valuable insights and potential policy responses.

Four distinct scenarios are presented within the study. It is important to emphasise that the values used in the model are expressed in real terms as of 2024. Consequently, in all cases, these values must be adjusted for inflation to ascertain their nominal levels, given that inflation constitutes a major risk factor for pension systems (Søren, 2017). Each scenario presents an optimal solution aimed at addressing the intertwined challenges of economic sustainability, social justice, and demographic shifts. In doing so, the model incorporates an appropriate weighting of the penalty function components while accounting for their interactions.

4.1. Sustaining social welfare regarding retirement age

The results related to the first scenario, which prioritises social welfare to support the most vulnerable segments of society while maintaining the current retirement age, are illustrated in Figure 4. By analysing the figure, it can be observed how the decision maker has to adjust each decision parameter in order to obtain the optimal solution for the strategy they have defined, as conveyed by the priority weights. The priority weights are: W=0.35; M=0.35; B=0.05; C=0.05; D=0.05; E=0.05; and G=0.05.

Figure 4: First scenario: sustaining social welfare regarding retirement age

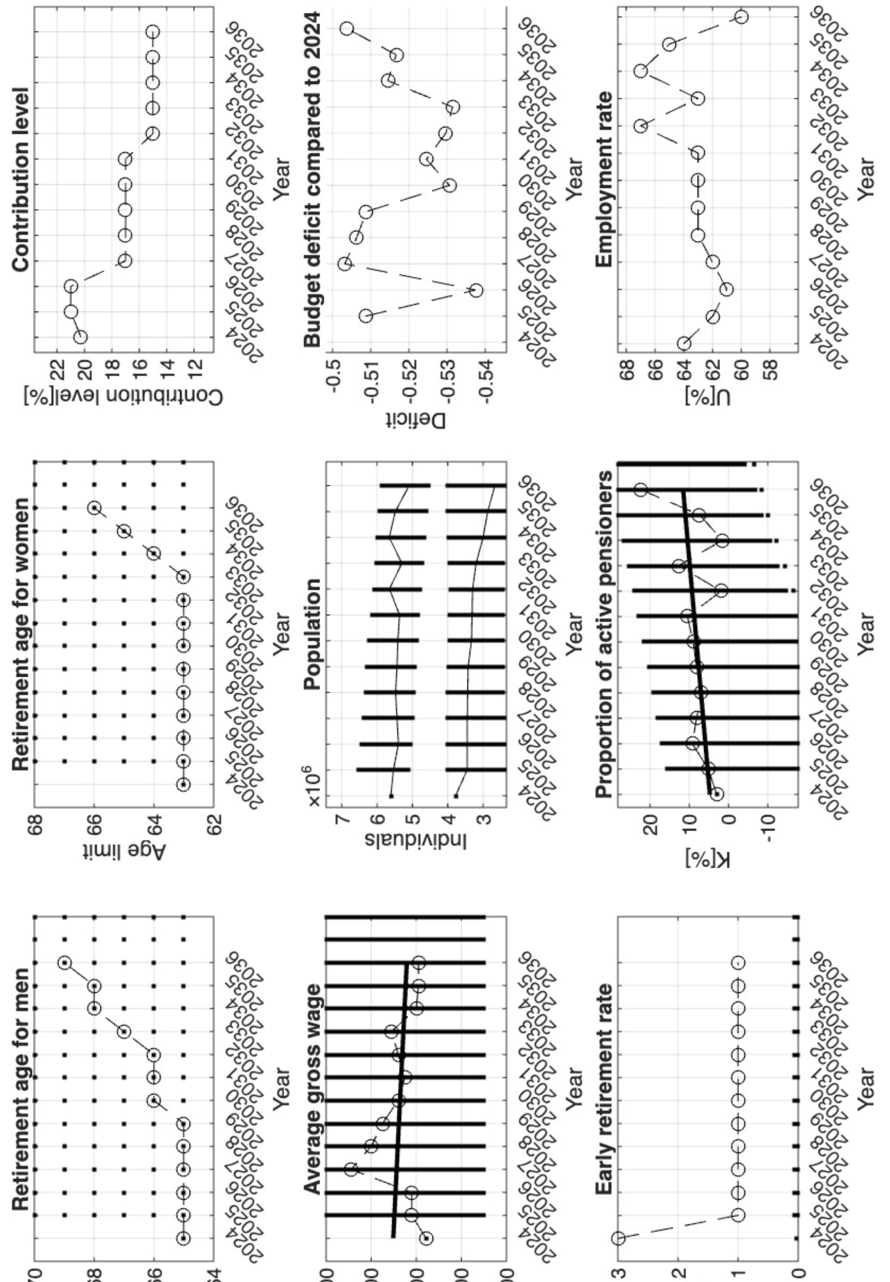


Source: Author's calculations

Consequently, 70.5% of the weighting parameters focus on achieving the designated objective. With respect to the retirement age, the optimal solution remains at the current levels: 65 years for men and 63 years for women. The optimal trajectory is instead achieved through adjustments in contribution rates, average wages, early retirement rates, active retiree ratios, and employment rates. In 2026-2027 and in 2031, a maximum contribution rate of 25% is required for the first pillar, which then gradually decreases to 19%, falling below the current level. Alternatively, from 2029, policymakers may opt to allocate the 1.25% reduction from the 2024 level to the second pillar. Regarding average wages, a national average of 9,000 lei in 2024 real terms is projected as a local maximum for 2034. Concerning the system's deficit, reductions of at least 52% (in 2031) and up to 55% (in 2033) are achievable compared to the 2024 baseline. The early retirement rate remains constant at 1% throughout the period. The proportion of active retirees is expected to gradually increase, reaching 22% by 2033. For the employment rate, only a 3% improvement from the 2024 level is necessary by 2036. Implementing this scenario requires ensuring dynamic economic growth, stimulating employment, and encouraging the retention and reintegration of the retired population into the labour market.

The first scenario has a negative impact on employees, as higher contribution rates reduce their net wages. To counterbalance these effects, real wage growth must be stimulated through vigorous economic policies aimed at boosting productivity. Furthermore, labour-market wages can be improved by emphasising adult education and retraining programmes, thereby enhancing human capital and mitigating the wage reductions caused by increased contributions. Training the labour force should therefore be a priority policy objective, as investment in human capital can raise wages (Schultz, 1971). Another important step in achieving the optimal scenario is to motivate retirees to remain active in the labour market. According to Article 54 of the Implementation Norms of the Pension Law (Law No. 360/2023), an even more favourable outcome may be achieved if pensioners voluntarily postpone retirement in anticipation of higher future pension benefits. In addition to this, it is important to note that increasing the value of the pension only by inflation and decoupling it from the national average gross wage risks widening a social gap between the active and inactive population and may contribute to the impoverishment of the pensioner age group. This has a coercive effect on pensioners to supplement their pension benefits with wages and not to leave the labour market. In this context, adequate health status and the state's healthcare system become critical considerations for enabling longer labour-market participation.

Figure 5: Second scenario: sustaining broad social welfare



Source: Author's calculations

4.2. Sustaining broad social welfare

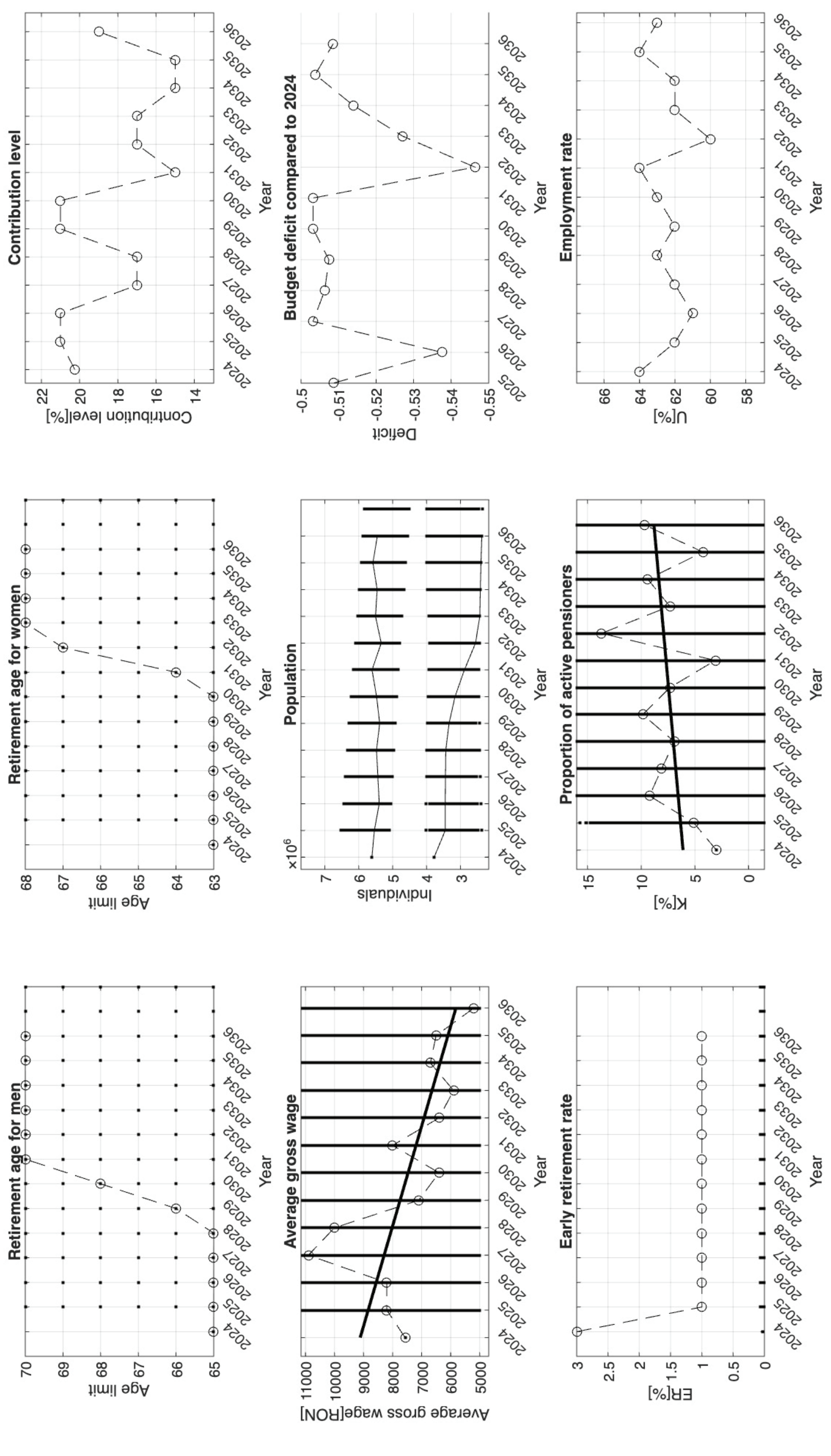
In the second scenario, the objective is to maintain the current level of broad social welfare with minimal reduction, considering both the retirement age and the contribution burden on employees. The results are illustrated in Figure 5. The following priority weights were applied: M=0.25; W=0.205; B=0.125; C=0.07; D=0.085; E=0.15; G=0.07.

This means that 80% of the weighting parameters serve a dual purpose. Regarding the retirement age for males, it is projected to increase to 66 years by 2030, to 67 years by 2033, and to 69 years by 2036. Thus, the increase commences in 2030 – a year deemed demographically critical. As for females, the retirement age must rise by one year annually after 2033, reaching 66 years by 2036. Consequently, a three-year gap emerges between the two statutory retirement ages. The contribution rate attains a local maximum of 21% during 2025-2026, then declines to 17% between 2027 and 2031, and further decreases to 15% in the period 2032-2036. This reduction improves the well-being of the employed, although it simultaneously worsens the situation of retirees. National average wages are expected to increase gradually until 2027, reaching a real-value local maximum of 10,900 lei (in 2024 terms), then falling to 8,500 lei by 2031 and to 7,900 lei by the end of the period under consideration. The deficit can be maintained at a level that is at least 50% lower than the real deficit of 2024, with a local minimum reduction of 54%. The proportion of pensioners receiving age-related reductions remains constant at 1% throughout the period. Meanwhile, the share of active retirees follows a linear upward trend, reaching a maximum of 22% by the end of the period. This parameter is thus considered to be the key factor in the implementation of the scenario. The employment rate must improve by 3% by the end of the period relative to 2024, although it is projected to drop to 63% in the critical year of 2030. In this scenario, the current retirement age is no longer sustainable, and the reduction in the contribution rate can only be achieved at the expense of, and alongside, the activation of the retired population.

4.3. Economic sustainability

As presented in Figure 6, the third scenario examines what happens to the parameters when deficit minimisation is the main pension policy objective, with the following coefficient values: M=0.05; W=0.05; B=0.05; C=0.05; D=0.7; E=0.05; and G=0.05.

Figure 6: Third scenario: economic sustainability



Source: Author's calculations

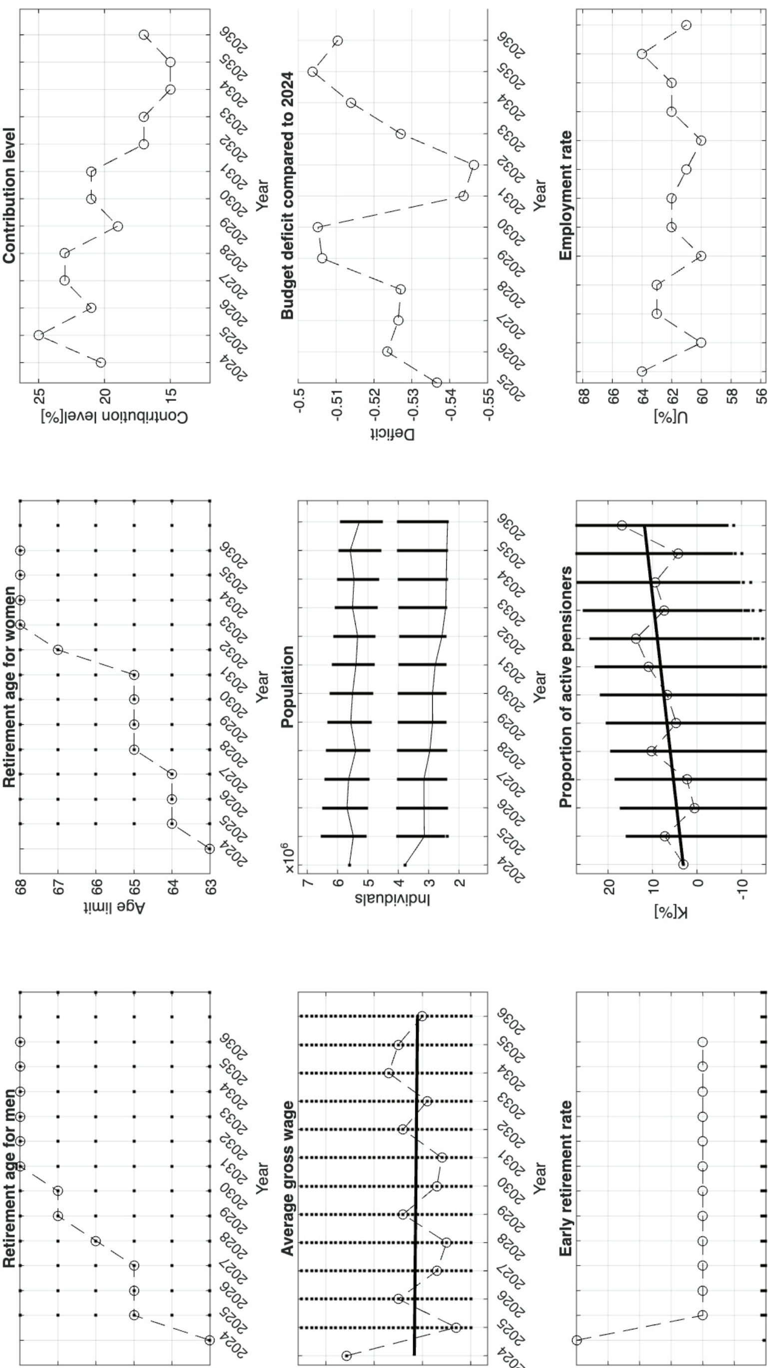
In this scenario, the retirement age remains at the current level until 2028 for men and 2030 for women, after which it increases to 70 years for men in 2031 and to 68 years for women in 2033. The contribution rate reaches a local maximum of 22%, but at its local minimum during the period under review (2034-2035), it drops to 15%. The national average gross wage reaches 10,900 lei in 2027; however, a linear trend with a negative slope can be fitted to the data, indicating a declining wage level in real terms, consistent with a recessionary scenario. The population's labour potential is fully utilised. The deficit is reduced by 50-55% in real terms compared to the deficit in 2024. The share of early retirees remains at 1%. For retirees, an employment rate of 13.7% is needed by 2032 at the local maximum, followed by a maximum of 10% in subsequent years. Regarding the employment rate, a ratio between 60-64% is required, without exceeding the 2024 value.

The third scenario represents a recessionary outlook, characterised by a declining trend in real wages and a falling employment rate. Nonetheless, even in this challenging economic environment, the deficit is successfully reduced – achieving an average reduction level of approximately 50%, similar to the previous scenarios – primarily through measures such as increasing the retirement age and increasing the employment of retirees.

4.4. Equal priority scenario

The optimal solution for equal priority weights is presented in Figure 7. For both sexes, the increase in retirement age is staggered, with the critical year 2030 requiring an age of 69 for men and 65 for women. The male retirement age will reach its upper limit by 2031 and the female by 2033.

Figure 7: Equal priority scenario



Source: Author's calculations

The contribution rate is projected to reach 25% by 2025, after which it gradually declines to 15%, with the possibility of stabilising at 17% in the final years of the period. The difference between the 2024 contribution level and the optimal level may be considered a positive addition when allocated to the second pillar. At the 2024 real level, the gross national average wage is expected to range between 5,300 and 6,700 lei; thus, being lower than the 2024 level, no additional resources need to be allocated to this area under the optimal scenario. During this period, the deficit of the Romanian state pension system is projected to decrease by 50-54% relative to the 2024 deficit, reaching its lowest level by 2032. The proportion of early retirees remains constant at 1% throughout the entire period. Meanwhile, the share of active pensioners gradually increases, reaching its peak of 17% at the end of the period. The employment rate is expected to remain between 60% and 64%, thereby not exceeding its current level. An inverse relationship can be observed between the employment rate and the proportion of active pensioners, as the system compensates for the reduced pool of contributors through the employment of pensioners. This balanced approach reflects the compromises between fiscal sustainability and social justice during a more recessionary period, when real wage growth is not feasible.

The simulation results confirm that policy interventions confined to a single dimension are insufficient to ensure long-term sustainability, as adjustments implemented in one domain inevitably generate spillover effects in the others. The findings align with the existing literature, which emphasises that the impact of demographic processes is substantially mediated by labour market conditions and institutional arrangements (Villanueva-García et al., 2025).

The institutional and legal dimensions also play a pivotal role. The results demonstrate that statutory retirement age regulations, eligibility conditions, and contribution rules fundamentally shape both the sustainability of the pension system and the adequacy of pension benefits. This is in line with findings from dynamic optimisation studies showing that isolated increases in the statutory retirement age may trigger unintended behavioural responses, such as shifts towards disability or early retirement (Fehr & Fröhlich, 2023; Nivalainen & Ilmakunnas, 2025).

From a methodological perspective, the results further contribute to literature on the dynamic optimisation of pension reforms. Studies examining the optimal timing of retirement age increases indicate that gradual, dynamically optimised reform paths are associated with substantially lower welfare losses than one-off, discrete policy interventions (Zhang & Zhu, 2024).

5. Conclusions

The study presents four optimal scenarios based on predefined priority criteria for pension system policies, enabling an examination of the system's dynamics along seven variable parameters: retirement age for women and men, contribution rate, gross national average wage, early retirement rate, proportion of active pensioners, and employment rate. The novelty of the approach lies in its optimisation process; using the Bellman functional within a penalty function integrated into the model, the decision maker can specify the weight parameters associated with each decision variable to formulate additional optimal pension system policies. Thus, the model not only determines the values of its components but also illustrates how these parameters should evolve and when strategic decisions should be made, to minimise the social and economic costs relative to the state of the Romanian public pension system in 2024, based on the established priority factors.

The added value of this study lies in its ability to bridge the gap between descriptive pension system projections and normative policy design. Unlike conventional simulation models that evaluate predefined reform paths, the proposed framework endogenously derives optimal policy trajectories by jointly considering demographic, economic, and institutional interactions within a dynamic optimisation setting. By explicitly accounting for transition costs and intertemporal trade-offs, the model provides decision makers with guidance not only on which policy parameters should be adjusted, but also on the appropriate timing and sequencing of reforms. This approach enhances the analytical relevance of pension system modelling by aligning long-term sustainability objectives with short- and medium-term social and economic constraints, thereby offering a more realistic and policy-relevant basis for pension reform design.

The results of the optimal scenarios indicate that, while maintaining the current retirement age may offer protection to vulnerable elderly groups, such protection is only feasible if it is accompanied by an increase in contribution rates – a measure that could, however, negatively impact the net wages of the employed. To mitigate these adverse effects, it is essential to stimulate real wage growth through robust economic policies aimed at enhancing productivity, complemented by strategic investments in adult education, since investments in human capital increase its value (Schultz, 1971). In the optimal solution, an increasing dynamic in this area is observable, thereby supporting the first hypothesis, which states that maintaining the current retirement age as a primary objective cannot be optimally achieved solely by modifying the social security contribution rate. Moreover, in line with the second hypothesis, all examined scenarios underscore that policy measures designed to promote the extended labour market participation of pensioners must be prioritised, as they are crucial for reducing fiscal pressure and ensuring the overall sustainability of the system. This is particularly important given the anticipated adverse labour market effects associated with the retirement of baby boomers. In the near future, an imperative for decision makers is to adopt flexible employment regulations and introduce tax incentives that could effectively encourage pensioners to remain in or re-enter the labour market. Hungary provides a notable example, having already implemented tax reductions for pensioners. Furthermore, revising Romania's current practice of excluding pensioners employed in the public sector could further motivate them to remain active. The provisions of Article 54 of Law 360/2023, which include the option of voluntarily deferring retirement in exchange for higher future pension benefits, could serve as an effective policy instrument.

It is also important to recognise that adjusting pension benefits solely based on inflation, without linking them to the gross national average wage, may widen the socio-economic gap between the active and inactive segments of the population. Such a gap might compel pensioners to supplement their income through additional employment, raising broader questions regarding the sustainability of social protection systems and the challenges related to elderly health and healthcare provision. Based on the examined scenarios, regarding the economical sustainability of the system, a minimum 50% decrease of the real value of the 2024 deficit could have been achieved each year even in recessionary economic circumstances, confirming the third hypothesis. In this case, the optimal solution is to raise the retirement age. When the same priority weights are assigned to the decision parameters, the gradual increase in the retirement age represents the greatest challenge.

When compared with the findings of other studies, the findings presented in this paper reinforce the view that achieving both the fiscal sustainability and social equity in pension systems requires an integrated, multifaceted policy approach. The model confirms that balancing the objectives of deficit reduction, wage stability, and retirement age adjustments require a carefully calibrated combination of economic and social policy interventions, thereby justifying the use of the optimising models presented in this study.

A limitation of the study is that the simplified model relies on historical data and specific assumptions, which may not fully capture future economic and demographic uncertainties. Future research should aim to incorporate stochastic elements into the model and pursue empirical validations in diverse contexts. Moreover, comparative analyses involving multiple countries or regions could further refine our understanding of the interactions between pension policy and broader socio-economic outcomes.

In summary, the dynamic pension model provides valuable insights into the trade-offs involved in pension system reform. The study lays a solid analytical foundation for designing policy interventions that balance fiscal discipline with social welfare. Moreover, it outlines clear directions for future research to enhance the model's applicability and empirical reliability.

The current model is robust, as it incorporates computed inputs based on projected population trends for the coming years. A future development goal could be to transform the model into a probabilistic framework that incorporates random variables. It would also be advisable to include further forward-looking decision parameters. In addition, the examination of gender differences in retirement age and the modelling of the effects created by eliminating these differences represent further potential research directions. Finally, as mentioned in the introduction of this paper, transforming the dynamic system into an adaptive system to find its internal equilibrium could be another possibility of future model development.

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Dinamička optimizacija i analiza scenarija rumunjskog javnog mirovinskog sustava

Annamária Lőrincz[1]

Sažetak

Literatura o održivosti javno financiranih mirovinskih sustava pretežno je usredotočena na dugoročne demografske i fiskalne projekcije te njihove očekivane posljedice. Znatno se manje pozornosti posvećuje izričitoj identifikaciji optimalnih javnopolitičkih rješenja koja istodobno minimiziraju ekonomske i socijalne troškove. Cilj je ovog rada odgovoriti na nedostatak u istraživanjima integriranjem donošenja odluka o mirovinskoj politici u okvir dinamičke optimizacije temeljen na Bellmanovoj jednadžbi, čime se omogućuje identifikacija ekonomski i društveno optimalnih politika. U radu se ispituje može li se dugoročna održivost rumunjskog javnog mirovinskog sustava poboljšati optimalnim vremenskim usklađivanjem političkih intervencija, uz istodobno ograničavanje ekonomskih i socijalnih opterećenja. Predloženi model integrira demografsku dinamiku, ponašanje na tržištu rada i fiskalna ograničenja u jedinstveni analitički okvir. Optimizira se sedam ključnih varijabli odlučivanja, uključujući dob umirovljenja žena i muškaraca, stopu doprinosa za mirovinsko osiguranje, nacionalnu prosječnu bruto plaću, stopu prijevremenog umirovljenja, udio aktivnih umirovljenika te stopu zaposlenosti. Simulacije scenarija za razdoblje 2024.-2036. pokazuju da se održavanje trenutačne dobi za umirovljenje ne može optimalno postići isključivo prilagodbama stope doprinosa. Rezultati naglašavaju ključnu ulogu produljenog sudjelovanja umirovljenika na tržištu rada, koje znatno smanjuje fiskalni pritisak i doprinosi dugoročnoj održivosti sustava. Prikazana metodologija i analizirani scenariji nisu relevantni samo za Rumunjsku, već se mogu prilagoditi i mirovinskim sustavima drugih zemalja, čime se podupire integrirani i višedimenzionalni pristup oblikovanju mirovinskih politika.

Ključne riječi: *javni mirovinski sustavi, dinamičke scenarijske analize, optimizacija, Rumunjska, politike mirovinskog sustava*

JEL klasifikacija: *C53, H55, H62, I38*

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Effects of Working Capital Management on the Profitability of Pharmaceutical Wholesale Companies in Croatia*

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Abstract

The main objective of this paper is to examine the relationship between working capital management and the profitability of companies engaged in the wholesale distribution of pharmaceutical products to pharmacies, hospitals, and other healthcare institutions in Croatia. This objective arises from the research question of whether working capital management has the same impact on the profitability of micro and small companies as it does on medium and large companies. Based on a sample of 157 companies observed over the period from 2015 to 2024, a panel data analysis was conducted to examine the impact, intensity, and direction of key working capital management factors—days of receivables collection (DCR), days of inventory stocked (DIS), and days of payment to suppliers (DPS)—on return on assets (ROA). The results indicate that DCR, DIS, and DPS have statistically significant negative effects on ROA, and that the COVID-19 pandemic and inflation further reduced ROA. Importantly, company size significantly moderates the effect of DPS: the effect remains negative for micro and small companies but becomes positive for medium and large companies. The findings suggest that managers should pay particular attention to working capital management, especially supplier payment policies, and adapt these practices to firm size in order to improve profitability and maintain financial stability during periods of economic uncertainty.

Keywords: *wholesale trade, pharmaceutical products, working capital management, profitability, COVID-19*

JEL classification: *G30, G32, G39*

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1. Introduction

This paper focuses on the management of short-term decisions, that is, decisions that require continuous monitoring of business processes by management to enable rapid adjustments to emerging market changes, as well as to changes within the company itself. These decisions are related to the management of working capital, specifically current assets and current liabilities. The importance of working capital management is reflected, on the one hand, in maintaining a company's liquidity and solvency and, on the other hand, in achieving a level of profitability that increases the company's value and consequently creates wealth for its owners. Although working capital management has been widely recognized in the literature, and it gained even greater importance during periods of financial crisis and the COVID-19 pandemic. Modern companies face numerous challenges for which management must be adequately prepared. Given the current geopolitical tensions, the risk of disruptions in international supply chains is unavoidable, which may consequently lead to increased transaction costs, longer delivery times, and deterioration in relationships with suppliers. At the same time, delivery delays may disrupt both production processes through inventory shortages and distribution processes involving finished goods. Furthermore, delays in delivery and failure to fulfil contractual obligations toward customers may result in contract cancellations, negatively affecting working capital through reduced cash inflows and an extended cash conversion cycle. Management in modern companies must therefore be prepared for such situations and continuously maintain an adequate level of liquidity while ensuring that the company's profitability is not compromised.

Effective management requires maintaining an optimal balance between profitability and liquidity, as well as between profitability and business risk. Excessive investment in working capital reduces risk but simultaneously lowers profitability. Conversely, lower investment increases the risk of maintaining the company's liquidity, while at the same time increasing the probability of achieving higher profitability. Based on previous research, several key determinants of working capital management that influence corporate profitability have been identified at the company level. These include the number of days required to collect receivables from customers, days of inventory stocked, days of payment to suppliers, company size, inflation, and GDP growth rate. However, the direction and intensity of the impact of each factor may vary across companies operating in different industries and of different sizes.

Previous findings indicate the existence of positive, negative, as well as statistically insignificant relationships between profitability and working capital management. The results vary depending on the country, company size, and the industry in which the company operates. The study Annual Global Working Capital Survey (PwC,

2015) identifies four main factors influencing working capital requirements: the sector in which the company operates, the level of economic development of the region, company size, and the importance attributed to cash and working capital management. Although it is often assumed that companies operating within the same sector have similar working capital requirements, significant differences exist in practice due to varying levels of managerial efficiency in managing working capital components. More efficient working capital management is more frequently observed in developed economies with institutionally stable market environments and among large companies. Conversely, small companies, despite their greater need to optimize working capital, often possess more limited managerial and financial capacities for their effective management. Cash and working capital management are crucial for maintaining a company's liquidity and financial stability. Nevertheless, management often focuses on external financing through banks or investors rather than generating additional free cash flows through the optimization of working capital.

This paper focuses on companies engaged in the wholesale distribution of pharmaceutical products (NACE Rev. 2 – 46.46) in Croatia, including the distribution of medicines and other pharmaceutical products to pharmacies, hospitals, and other healthcare institutions. The wholesale trade sector comprises companies engaged in the resale of goods without their transformation and represents an intermediate stage in the distribution chain. Within the pharmaceutical supply chain, the first stage is the pharmaceutical industry, namely the manufacturing of pharmaceutical and medical products, where the two most important business activities are research and development and the production of medicinal products. This is followed by the wholesale distribution trade of pharmaceutical products, which involves the distribution and sale of medicinal products to pharmacies, retail outlets, and hospitals, thereby ensuring the availability of medicinal products to end users, namely consumers and patients. According to the Ordinance on Good Distribution Practice for Medicinal Products (2013), the wholesale distribution of medicinal products includes procurement, receipt, storage, transportation, sale, and delivery, excluding dispensing to the final consumer, as well as the import, export, and transfer of medicinal products. According to the Medicines Act (2025), wholesalers may procure medicinal products directly from manufacturers, importers, and other wholesalers licensed by the competent authority, while supplying pharmacies, healthcare institutions, and other authorized entities.

Most of the European countries regulate wholesale markup and margin schemes, at least for reimbursable medicinal products. Most Member States apply regressive margins (Matteucci & De Santis, 2025). In Croatia, wholesale margins are regulated by the Ordinance on Amendments to the Ordinance on the Criteria for Determining the Maximum Permitted Price of Medicinal Products (2023). According to Article 4 of the Ordinance, the wholesale price of a medicinal product includes the wholesale margin and other related costs. The wholesale price is determined by increasing the manufacturer's price by the value of the differentiated wholesale margin in accordance with Table III, which forms an integral part of the Ordinance. Croatia applies a differentiated wholesale margin system, whereby the applicable margin varies across price ranges from 4.5% to 8.5%, subject to a maximum cap of EUR 4,000. The differentiated margin system is intended to reduce medicine prices and control healthcare system costs. However, pharmaceutical wholesalers advocate higher margins for lower-priced medicines and argue that the maximum margin of 8.5% is insufficient to cover distribution costs, the high standards required for the storage of medicinal products, and the risks associated with potential product withdrawals due to expiration dates. Additional pressures arise from inflation and financing risks related to delayed payments, which most commonly occur with hospitals and account for approximately 45–50% of the total sales of pharmaceutical wholesalers.

Payment periods for pharmaceutical wholesalers are generally longer than those in other wholesale sectors. Due to delays in the settlement of obligations by healthcare institutions, pharmaceutical manufacturers often allow wholesalers extended collection periods for accounts receivable. The pharmaceutical manufacturer grants a permissible delay period to the wholesaler, while the wholesaler, in turn, applies a trade credit strategy toward hospitals (Karuppasamy & Uthayakumar, 2019). For pharmaceutical manufacturers, minimizing the collection period is not necessarily the primary objective, and they may accept a more aggressive credit policy to avoid direct transactions with healthcare administration. Inventory policy is strongly influenced by demand conditions. Most inventory models assume that the demand rate is constant. However, in the healthcare sector, demand for the pharmaceutical products is dynamic and varies over time (Karuppasamy & Uthayakumar, 2019). At the same time, pharmaceutical wholesalers cannot afford stockouts because these products are essential for protecting human health and life. Consequently, the optimal inventory level in pharmaceutical companies is generally higher than in other wholesale sectors.

In Croatia, there are currently no studies examining the relationship between working capital management and the profitability of pharmaceutical wholesale companies; therefore, this study represents the first research of this kind. Considering the specific characteristics of working capital management in pharmaceutical wholesalers—namely the need to ensure the continuous availability of medicines while simultaneously facing long collection periods, particularly from healthcare institutions—this research aims to provide new insights for the management of pharmaceutical wholesalers regarding the impact of working capital on profitability, with the goal of helping companies maintain liquidity and stable sources of financing. Accordingly, the following hypothesis is formulated: Working capital management does not have the same effect on the profitability of medium and large companies as it does on micro and small companies in the pharmaceutical wholesale sector.

The paper is structured as follows. The introductory chapter defines the research problem and subject and presents the research hypothesis. The second chapter provides a literature review, including the theoretical framework and an overview of empirical studies on working capital management. The third chapter presents the data and the methodological approach used in the analysis in a transparent manner. The fourth chapter presents the results of the empirical analysis and provides an explanation of the findings. The fifth chapter discusses the economic significance of the results, while the sixth chapter concludes with the author's final remarks.

2. Literature review

Traditionally, in a broader sense, gross working capital is understood as working capital and is defined as a company's investment in current assets. However, considering the interdependence between investments in current assets and the financing of those assets, gross working capital includes not only the total current assets of a company but also the methods used to finance those assets (Orsag, 2015). According to the duration of use, gross working capital can be divided into permanent and temporary gross working capital. Permanent current assets represent the minimum level of investment in current assets required for a company to maintain its sales, while any level above that represents temporary current assets (Pepur et al., 2015). Permanent current assets include all categories of inventories, namely raw materials, work in progress, finished goods, and merchandise, whereas temporary current assets consist of cash, marketable securities, and accounts receivable (Orsag, 2003). Net working capital is commonly defined as the difference between a company's current assets and current liabilities (Sen & Oruc, 2009; Brigham & Ehrhardt, 2011; Gitman & Zutter, 2011; Orsag, 2015), that is, the portion of current assets financed by long-term sources. A company may have either positive or negative net working capital. Positive net working capital indicates that a company is in good financial condition and can meet its short-term obligations through the sale of current assets or the collection of receivables from customers. In contrast, negative net working capital indicates that a company is unable to meet its debt obligations even if it liquidates its current assets (Seyoum et al., 2016), suggesting that it is not generating sufficient sales to maintain liquidity. Net operating working capital, also referred to as non-cash working capital, is defined as the sum of inventories and accounts receivable minus accounts payable. Smith (1980) was among the first authors to highlight the importance of working capital management due to its impact on a company's profitability and risk, and indirectly on its market value. Following this early contribution, numerous authors have confirmed the importance of an efficient working capital management policy.

Numerous empirical studies have examined the relationship between working capital management and corporate profitability and have identified the key determinants of working capital management that influence the level of profitability. The results obtained vary depending on company size, the country in which the company operates, and the industry in which it operates. Most of the research on working capital has been conducted in countries with well-developed capital markets and a large share of manufacturing companies, such as India, Pakistan, China, the United States, the United Kingdom, Germany, and Belgium. In contrast, there is a lack of research in transition and Central and Eastern European (CEE) countries, particularly sector-specific studies. Although most studies provide empirical evidence of a negative relationship between the level of working capital and profitability, the literature reveals considerable heterogeneity in the results. Some studies report a positive effect, while others do not confirm the existence of a statistically significant relationship between working capital and profitability. Working capital policies differ across sectors and also change over time within each sector (Filbeck & Krueger, 2005).

Most empirical studies confirm a negative relationship between accounts receivable and corporate profitability (Gill et al., 2010; Mathuva, 2010; Akoto et al., 2013; Gul et al., 2013; Tauringana & Afrifa, 2013; Wesley et al., 2013; Almazari, 2014; Nigatu, 2015; Pais & Gama, 2015, among others), whereas Sharma and Kumar (2011) report a positive relationship in their study. In contrast, Sen and Oruc (2009), Raheman et al. (2010), Makori and Jagongo (2013), Enqvist et al. (2014), and Seyoum et al. (2016) do not find a statistically significant relationship between accounts receivable and corporate profitability. Similarly, existing empirical research also confirm a negative relationship between inventory levels and profitability (Sen & Oruc, 2009; Raheman et al., 2010; Sharma & Kumar, 2011; Gul et al., 2013; Almazari, 2014; Enqvist et al., 2014; Nigatu, 2015; Pais & Gama, 2015; Seyoum et al., 2016, among others). Mathuva (2010) and Makori and Jagongo (2013) report a positive relationship between inventory levels and profitability, while Gill et al. (2010), Tauringana and Afrifa (2013), and Wesley et al. (2013) do not find a significant relationship. Although most researchers initially expect a positive relationship between accounts payable and profitability, most empirical studies report a negative relationship (Sen & Oruc, 2009; Sharma & Kumar, 2011; Tauringana & Afrifa, 2013; Almazari, 2014; Enqvist et al., 2014; Pais & Gama, 2015; Seyoum et al., 2016, among others). Studies such as Mathuva (2010), Gul et al. (2013), Makori and Jagongo (2013), and Farhan et al. (2021) find a positive relationship, while several other studies do not report a statistically significant association (Gill et al., 2010; Raheman et al., 2010; Akoto et al., 2013; Wesley et al., 2013; Nigatu, 2015, among others). These findings indicate that the relationships between company-level working capital management components and corporate profitability vary across countries, company sizes, and industries.

Since this study analyses the period from 2015 to 2024, it also includes the period affected by the COVID-19 pandemic. Several studies have examined the impact of working capital management on corporate profitability before and during the COVID-19 pandemic. Shen et al. (2021) analysed the impact of COVID-19 on the corporate performance of Chinese listed companies and found a negative effect on company performance. Similarly, Hamshari et al. (2022) examine the impact of the pandemic on working capital management practices of companies in the financial sector listed on the Amman Stock Exchange. Their results reveal that the COVID-19 pandemic had a significant and negative impact on working capital management and that companies tended to adopt a relatively conservative approach to working capital management during this period. The findings also indicate that the pandemic crisis triggered changes in working capital management practices. Yousaf (2022), in a study of Czech manufacturing companies, concludes that the efficiency of working capital management was significantly affected by the COVID-19 pandemic. Other studies focused on whether the pandemic altered the relationship between working capital management and company performance. Liu et al. (2024) examine the impact of working capital management on the financial performance of companies in the Chinese agri-food sector from 2006 to 2021 and assessed whether this relationship differed during the 2008 financial crisis and the COVID-19 crisis. Their results show that the relationship between working capital management and financial performance was more strongly affected during the COVID-19 crisis. However, the evidence is not entirely consistent. Zimon and Tarighi (2021) investigate the effects of the COVID-19 pandemic on working capital management policies among Polish small and medium-sized companies and conclude that the pandemic crisis did not significantly alter their working capital management strategies.

3. Methodological approach

After reviewing the relevant literature and numerous empirical studies, the variables used in this research were selected in accordance with the hypothesis that "*working capital management does not have the same effect on the profitability of medium and large companies as it does on micro and small companies in the pharmaceutical wholesale trade sector*". These variables are presented in Table 1, together with their description, definition and role. In addition to the variables used to measure profitability and working capital management during the observation period, the model also includes control and moderating variables.

Table 1: Variables with full term, abbreviation and explanation

Variable	Description	Definition	Role
Return on assets	Earnings before interest and taxes to the total assets (%)	$ROA = \frac{EBIT}{TA} 100\%$	Dependent
Days of receivables collection	Ratio between the number of days in a year and receivables turnover	$DCR = \frac{AR * 360}{Sales}$	Independent
Days of inventory stocked	Ratio between the number of days in a year and inventory turnover	$DIS = \frac{INV * 360}{COGS}$	Independent
Days of payment to suppliers	Ratio between the number of days and payables turnover	$DPS = \frac{AP * 360}{COGS}$	Independent
Size	Dummy variable (1 for medium and large companies and 0 otherwise)	$SIZ = \begin{cases} 0 \\ 1 \end{cases}$	Moderator
COVID	Dummy variable (1 for years during pandemic (2020, 2021 and 2022) and 0 otherwise)	$COVID = \begin{cases} 0 \\ 1 \end{cases}$	Control
Inflation rate	Annual inflation (%)	$INF = \ln \left(\frac{CPI_t}{CPI_{t-1}}\right) 100\%$	Control
GDP growth	Real GDP annual growth rate (%)	$growth = \ln \left(\frac{GDP_t}{GDP_{t-1}}\right) 100\%$	Control
Current liquidity	Ratio of current liquidity and current liabilities	$liquidity = \ln \left(\frac{asset_{it}}{liabilities_{it}}\right)$	Control

Source: Author's representation

Company-level variables were obtained from the Croatian Financial Agency (FINA, 2025), while macroeconomic variables such as inflation and GDP growth (company-invariant but time-varying variables) were obtained from the EUROSTAT database. Among the control variables, the current liquidity ratio represents the firm-level control variable. Its inclusion is appropriate because it reflects firms' short-term liquidity positions and serves as a robustness check to determine whether the main findings remain stable after controlling for firms' ability to meet current obligations with current assets.

Since the data were observed across multiple companies over a ten-year period (2015-2024), a panel data analysis was employed as the appropriate methodological approach due to repeated observations of the same units over time. In the corresponding panel model, the dependent variable is profitability, measured by return on assets (ROA). The independent variables include accounts receivables, inventories and accounts payables, the moderator variable is company size, while the control variables are COVID, inflation, and GDP.

$$ROA_{i,t} = \beta_1 DCR_{it} + \beta_2 DIS_{it} + \beta_3 DPS_{it} + \beta_4 SIZ_i \times DCR_{it} + \beta_5 SIZ_i \times DIS_{it} + \\ + \beta_6 SIZ_i \times DPS_{it} + \beta_7 COVID_t + \beta_8 INF_t + \beta_9 GDP_t + \mu_i + \varepsilon_{it} \quad (1)$$

The above equation represents a full panel model, which requires estimating 9 parameters in total, while μ_i is unobserved company-specific fixed effects and ε_{it} is idiosyncratic error term, assuming that individual effects are independent with error terms. This model is the one-way fixed effects (FE) panel, which does not consider a time-specific effect, because it is already partially captured by the COVID variable. In the one-way fixed effects (FE) panel model, the estimation is based on the within transformation, which eliminates unobserved time-invariant individual effects from the model. Specifically, the within estimator transforms the data by subtracting the time average of each variable for a given unit from the corresponding observed values. In the fixed-effects model, the constant term is omitted because the estimation is based on the within transformation (demeaning procedure), which removes time-invariant company-specific effects from the model. Consequently, the intercept is not estimated separately, as it is absorbed by the individual fixed effects. Ultimately, confirming the proposed hypothesis relies on testing the statistical significance of the interaction effects (coefficients β_4, β_5, β_6), which are represented in the model by multiplicative terms. These interactions capture the moderating role of company size in the relationship between working capital management indicators and profitability. If the estimated interaction effects are statistically significant, this indicates that the impact of individual working capital indicators differs between the two groups of companies. Furthermore, the sign and magnitude of the estimated coefficients provide information on the direction and strength of these differences, thereby revealing how the effects of specific working capital management indicators on profitability vary across the two groups of companies.

Company size is included as a moderator variable because the relationship between working capital management and profitability may vary depending on company size. Larger companies often have better access to financing and more efficient inventory management, which can alter the effect of working capital components on profitability. Several macroeconomic control variables are incorporated to isolate the effect of the main explanatory variables. The COVID variable captures the impact of the pandemic-related economic disruption, while inflation and GDP control for broader macroeconomic conditions that can influence companies' financial performance and operating environment. Including these control variables helps reduce omitted variable bias and improves the reliability of the estimated relationships in the panel model.

Several panel model specifications were estimated to obtain a clearer understanding of the impact of working capital management indicators on profitability. Specifically, the models were estimated both with all working capital management indicators included simultaneously and with the indicators introduced separately. Although these indicators are expected to be positively correlated, as they capture related dimensions of working capital management, the correlations are not sufficiently high to raise serious multicollinearity concerns. Estimating alternative model specifications is a common practice in empirical research, as it enables researchers to assess the robustness of the findings, identify the specification that best fits the data, and provide stronger support for testing the proposed hypothesis.

The analysis initially employed fixed-effects (FE) panel models as baseline specifications, as this approach allows for controlling unobserved company-specific heterogeneity that may be correlated with the explanatory variables. Following the estimation of the baseline models, a series of diagnostic tests was conducted to assess whether the assumptions underlying the selected specification were satisfied and to identify the most appropriate estimator for the analysis. These tests examined common panel data issues, including serial correlation, cross-sectional dependence and slope heterogeneity, as well as the overall suitability of fixed-effects relative to alternative panel estimators. If the assumptions required for the standard fixed-effects estimator were not satisfied, alternative estimators capable of producing valid and robust results were considered. Special attention was given to the structure of the variables included in the model. The COVID variable, inflation, and real GDP growth are time-varying variables that change over time but are identical across all companies within a given period. In contrast, company size is time-invariant but differs across companies. This distinction was considered when selecting and interpreting the appropriate panel model specification.

4. Empirical data and analysis

The units of analysis are companies engaged in the wholesale of pharmaceutical products (NACE Rev. 2 - 46.46), including the distribution of medicines, drugs, and other pharmaceutical preparations to pharmacies, hospitals, and other healthcare institutions. Although the number of such companies in Croatia is finite (574 companies observed over 10-year period), the panel dataset, when considering both its cross-sectional and time-series dimensions, does not represent a finite population in the statistical sense, as each company contributes multiple observations over time.

The sample selection criteria were based on data completeness and panel balance, ensuring that all companies included in the sample had available data for all variables and were continuously observed throughout the entire period from 2015 to 2024. This balanced panel structure is preferable because it enables more consistent estimation and facilitates model comparison. Applying these criteria resulted in a final sample of 157 companies, of which 123 were classified as micro or small companies and 34 as medium or large companies. It is also noteworthy that none of the selected companies changed their size classification during the observation period.

Table 2 presents descriptive statistics for the key variables used in the analysis, grouped by company size, while Table 3 reports the correlation coefficients between ROA, used as the measure of profitability, and the three working capital management indicators: days of receivables collection (DCR), days of inventory stocked (DIS), and days of payment to suppliers (DPS).

Table 2: Descriptive statistics

	Size	Min	Max	Mean	Sd
ROA	micro and small	-197.60	119.29	13.43	19.32
	medium and large	-27.73	104.03	13.31	15.80
DCR	micro and small	0.00	574.63	90.61	79.07
	medium and large	0.00	329.86	123.08	73.18
DIS	micro and small	0.00	1955.50	202.90	266.22
	medium and large	0.00	923.95	79.10	81.75
DPS	micro and small	0.00	1528.80	94.62	139.25
	medium and large	0.00	262.59	70.00	63.98

Source: Author's calculations in RStudio using data obtained from the Croatian Financial Agency (FINA, 2025)

According to Table 2 the average ROA is very similar across groups (13.43% for micro and small companies and 13.31% for medium and large companies), suggesting comparable levels of profitability. However, micro and small companies exhibit substantially greater variability (standard deviation of 19.32 vs 15.80) and more extreme minimum values, indicating higher financial instability. Regarding working capital management indicators, medium and large companies have a longer average collection period (DCR:123.08 versus 90.61 days), suggesting lower receivables collection efficiency. In contrast, micro and small companies hold inventories (DIS 202.90 versus 79.10 days) and delay payments to suppliers (DPS 94.62 versus 70.00 days) for considerably longer periods, reflecting less efficient and more volatile working capital management practices. Overall, larger companies appear to maintain more stable and controlled working capital policies, which may reflect stronger financial discipline and better access to external financing sources.

The correlation matrix between profitability and working capital management indicators, presented in Table 3, reveals several statistically significant relationships.

However, these results should be interpreted with caution, as they are based on pooled panel data and do not account for company-specific effects. ROA is negatively and significantly correlated with all working capital management indicators, suggesting that longer collection, inventory holding, and payment periods are associated with lower profitability. The strongest negative correlation is observed between ROA and DIS.

Table 3: Correlation matrix between key variables

	ROA	DCR	DIS	DPS
ROA	1			
DCR	-0.1666***	1		
DIS	-0.2332***	0.1004***	1	
DPS	-0.1777***	0.2214***	0.1262***	1

Note: ***, ** and * denote significance at 1%, 5% and 10% level

Source: Author's calculations in RStudio using data obtained from the Croatian Financial Agency (FINA, 2025)

The analysis begins with the estimation of fixed-effects (FE) panel models, as this approach controls for unobserved time-invariant heterogeneity across companies, thereby reducing omitted variable bias and providing more consistent estimates when company-specific effects are correlated with the explanatory variables. Several model specifications are estimated by sequentially introducing additional variables, including control variables and, subsequently, company size as a moderating dummy variable (equal to 1 for medium and large companies and 0 otherwise), resulting in a total of seven models presented in Table 4. The sequence of variable introduction was guided by their economic role in the model. The first three models include the main working capital management variables to assess their direct effects on profitability. Next, interaction terms with company size are introduced to examine potential moderating effects, while macroeconomic variables are added in the final models as controls to evaluate the stability and robustness of the estimated relationships. This hierarchical specification reflects the theoretical structure of the model rather than a data-driven variable selection procedure. Subsequently, a series of diagnostic tests is conducted to assess the validity of the fixed-effects assumptions and to determine the most appropriate estimator for the subsequent analysis. These tests evaluate whether alternative estimators that account for serial correlation, cross-sectional dependence, or slope heterogeneity are required, as such issues are common in panel data analysis. It should be noted that neither revenue nor revenue growth is included as a control variable because both are directly related to the calculation of return on assets, the dependent variable. Their inclusion could therefore lead to tautological relationships and biased inference.

Table 4: Fixed effect panel models

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DCR	-0.043***	-0.040***	-0.031***	-0.031***	-0.036***	-0.037***	-0.037***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)
DIS		-0.011***	-0.010***	-0.010***	-0.010***	-0.010***	-0.010***
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
DPS			-0.019***	-0.019***	-0.018***	-0.018***	-0.018***
			(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
COVID				-0.446**	-0.512**	-0.821***	-0.831***
				(0.221)	(0.225)	(0.302)	(0.3012)
DCR × SIZ					0.035	0.031	0.031
					(0.023)	(0.023)	(0.023)
DIS × SIZ					-0.000	-0.001	-0.001
					(0.012)	(0.012)	(0.012)
DPS × SIZ					0.054**	0.056**	0.056**
					(0.025)	(0.026)	(0.026)
INF						-0.147*	-0.163*
						(0.085)	(0.096)
GDP							0.034
							(0.076)
Num.Obs.	1,570	1,570	1,570	1,570	1,570	1,570	1,570
R2	0.20	0.38	0.54	0.55	0.57	0.58	0.59

Note: ***, ** and * denote significance at 1%, 5% and 10% level (standard errors in parenthesis)

Source: Author's calculations in RStudio using data obtained from the Croatian Financial Agency (FINA, 2025)

The models are estimated sequentially, with the gradual introduction of additional explanatory variables, interaction effects, and macroeconomic control variables, allowing for an assessment of the robustness and stability of the estimated parameters. Model 1 includes only DCR and shows a negative and statistically significant effect, indicating that a one-day increase in DCR reduces profitability by 0.043 percentage points (pp). This effect remains stable and highly significant across all subsequent models, although its magnitude slightly decreases when additional controls are introduced, ranging from -0.031 to -0.040 pp. This stability confirms that DCR is a robust negative predictor of ROA. Model 2 introduces DIS, which also exhibits a negative and statistically significant coefficient, suggesting that an increases in DIS by 1 day reduces ROA by 0.011 pp. The magnitude and significance remain unchanged across all specifications, indicating a consistent negative predictor of ROA. Model 3 adds DPS, which likewise exhibits a negative and statistically significant relationship with ROA (-0.019 pp). Model 4 introduces the COVID dummy variable, which has a negative and statistically significant effect. This implies that the pandemic period was associated with a substantial decline in ROA of 0.446 percentage points. The magnitude of this effect increases further in Models 6 and 7 (reaching -0.831 pp), indicating that, once company-size interactions and macroeconomic controls are considered, the adverse impact of the pandemic appears even stronger.

Models 5, 6, and 7 incorporate interaction terms between the key explanatory variables and company size (SIZE), allowing the effects of working capital management indicators on profitability to differ between micro and small companies and medium and large companies. The interaction between DCR and company size is positive but statistically insignificant, suggesting that the negative impact of DCR on ROA does not differ significantly across company size categories. Similarly, the interaction between DIS and company size is not statistically significant. However, the interaction between DPS and company size is positive and statistically significant at the 5% level (Model 6). This finding indicates that company size moderates the relationship between DPS and ROA. Specifically, the baseline effect of DPS (-0.018 pp) applies to micro and small companies, implying a negative relationship between DPS and ROA for these companies. For medium and large companies, the effect becomes positive, as indicated by the combined coefficient of -0.018 + 0.056 = 0.038 pp. This suggests that an increase in DPS is associated with higher ROA among medium and large companies, in contrast to its negative effect among micro and small companies. Model 6 introduces inflation, which has a negative and statistically significant coefficient, indicating that a one-percentage-point increase in inflation is associated with a 0.147 pp decrease in ROA. This finding suggests that macroeconomic instability may adversely affect company profitability. Model 7 additionally includes GDP growth, which exhibits a positive but statistically insignificant coefficient, indicating no clear relationship with ROA.

The explanatory power of the models increases with their complexity, with R^2 rising from 0.20 in Model 1 to 0.59 in Model 7, indicating an improved model fit as additional variables are introduced. However, Model 6 represents the most appropriate specification. It includes all key company-level variables, the COVID-19 effect, company size interaction terms, and inflation as a relevant macroeconomic control variable, while maintaining statistical stability and a satisfactory goodness-of-fit. Although Model 7 yields a slightly higher R^2, the GDP growth variable is not statistically significant and does not materially affect the estimated relationships. The results indicate that DCR, DIS, and DPS have statistically significant effects on ROA, while COVID-19 and inflation are associated with lower profitability. Importantly, company size significantly moderates the effect of DPS: the relationship remains negative for micro and small companies but becomes positive for medium and large companies.

To assess the appropriateness of the fixed-effects specification, several diagnostic tests were conducted. The results are presented in Table 5.

Table 5: Fixed effect panel models diagnostics

Model	Poolability test	Serial correlation test	Cross-sectional dependence test
(1)	1.2749**	3.5422***	4.8436***
(2)	1.6969***	3.7997***	4.2051***
(3)	1.6576***	3.7766***	4.3561***
(4)	1.6094***	3.7763***	4.7836***
(5)	1.3658**	3.7432***	2.4285**
(6)	1.2427**	3.7450***	2.7768**
(7)	1.2359**	3.7446***	2.6104**

Note: ***, ** and * denote significance at 1%, 5% and 10% level

Source: Author's calculations in RStudio using data obtained from the Croatian Financial Agency (FINA, 2025)

The diagnostic results presented in Table 5 reveal several important characteristics of the panel models estimated in the first stage of the analysis. The poolability test rejects the null hypothesis of slope homogeneity in all model specifications, indicating that pooled OLS is inappropriate and that unobserved heterogeneity across companies must be controlled for, thereby supporting the use of fixed-effects models. The Wooldridge test for serial correlation is highly significant in all models, indicating the presence of autocorrelation in the idiosyncratic error term. This violates the classical fixed-effects assumption of no serial correlation and may result in biased standard errors if left uncorrected. Furthermore, the Pesaran test for cross-sectional dependence is significant in all models, suggesting the presence of contemporaneous correlation across companies. Taken together, these findings support the use of fixed-effects models with robust standard errors that account for both serial correlation and cross-sectional dependence, such as Driscoll-Kraay standard errors, or alternatively, common correlated effects estimators, to ensure valid statistical inference.

Given the rejection of slope homogeneity and the presence of cross-sectional dependence, the Common Correlated Effects Mean Group (CCEMG) estimator is employed, as it allows for heterogeneous slope coefficients and accounts for unobserved common factors, thereby providing consistent estimates in heterogeneous panels. The CCEMG estimator is estimated for six model specifications, as GDP growth was not statistically significant in Model 7 and was therefore excluded from further analysis.

Table 6 presents the results obtained using the CCEMG estimator, which accounts for cross-sectional dependence, unobserved common factors, and heterogeneous slope coefficients across companies. Compared with the fixed-effects (FE) models, the CCEMG approach provides more robust estimates, particularly when companies are exposed to common macroeconomic shocks and other unobserved factors that affect all cross-sectional units simultaneously.

Table 6: Common Correlated Effects Mean Group models

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DCR	-0.101**	-0.063	0.057	0.136	-0.024	-3.410	-3.021
	(0.047)	(0.048)	(0.051)	(0.111)	(0.035)	(2.146)	(1.998)
DIS		-0.125*	0.073	-0.075	-0.031	0.055	0.054
		(0.067)	(0.107)	(0.205)	(0.024)	(1.329)	(1.325)
DPS			-0.137**	-0.121**	-0.020*	-0.265**	-0.273**
			(0.063)	(0.055)	(0.012)	(0.120)	(0.134)
COVID				-0.012*	-0.012*	-0.177**	-0.175**
				(0.007)	(0.007)	(0.081)	(0.080)
DCR×SIZ					0.003	-0.899	-0.641
					(0.002)	(0.894)	(0.775)
DIS×SIZ					-0.004*	0.202	0.182
					(0.002)	(0.987)	(0.747)
DPS×SIZ					0.005*	0.480**	0.477**
					(0.002)	(0.227)	(0.225)
INF						-0.633*	-0.640*
						(0.335)	(0.362)
LIQUDITY							0.002
							(0.003)
Num.Obs	1,570	1,570	1,570	1,570	1,570	1,570	1,570
R2	0.31	0.42	0.32	0.47	0.55	0.60	0.61

Note: ***, ** and * denote significance at 1%, 5% and 10% level (standard errors in parenthesis)

Source: Author's calculations in RStudio using data obtained from the Croatian Financial Agency (FINA, 2025)

In Model 1, DCR exhibits a negative and statistically significant coefficient, which is consistent with the fixed-effects results. However, the coefficient becomes statistically insignificant and unstable in magnitude once additional controls and correlated effects are introduced (Models 2-6). This suggests that part of the negative relationship observed in the FE models may reflect common macroeconomic or cross-sectional influences rather than purely company-level effects. Model 2 introduces DIS, which has a negative and weakly significant coefficient (-0.125 pp), again consistent in direction with the FE models, where DIS also exhibited a negative and statistically significant effect. However, the coefficient becomes statistically insignificant in

Models 3–6, indicating that the evidence for a persistent effect of DIS is weaker under the CCEMG specification.

Model 3 introduces DPS, which exhibits a negative and statistically significant coefficient, indicating a consistent negative relationship with ROA. The persistence of this effect across both FE and CCEMG estimators suggests that DPS is one of the most robust determinants of profitability. The COVID variable becomes negative and statistically significant once introduced, with coefficients ranging from -0.012 to -0.177 pp. This finding is consistent with the FE results, which also indicate a significant adverse effect of the pandemic on ROA. Although the magnitude of the estimated effect differs across estimators, both approaches clearly suggest that the pandemic period had a negative impact on company profitability. The interaction effects reveal important heterogeneity across companies of different sizes. The interaction between DPS and company size is positive and statistically significant, consistent with the fixed-effects results, where the same interaction term was also positive and statistically significant. In both estimators, the results indicate that DPS has a negative effect on profitability for micro and small companies, whereas this effect becomes positive for medium and large companies. This consistency across estimators strengthens the conclusion that larger companies are better able to absorb or benefit from changes in DPS than micro and small companies. The interaction between DIS and company size is weakly negative and only marginally significant, whereas the interaction between DCR and company size is statistically insignificant. Inflation enters the model with a negative and statistically significant coefficient, suggesting that inflation represents an important common factor affecting company profitability. The explanatory power of the CCEMG models increases steadily, with R^2 rising from 0.31 to 0.60. Model 6 provides the most comprehensive specification, incorporating company-level determinants, pandemic effects, interaction terms, and macroeconomic controls while accounting for cross-sectional dependence and slope heterogeneity. Robustness is confirmed in the extended model (Table 6, Model 7), as including the current liquidity ratio (current assets/current liabilities) in the CCEMG specification does not substantially change the direction or statistical significance of the estimated relationships. Moreover, the current liquidity ratio has a positive coefficient, suggesting that liquidity may support profitability, although the estimated effect is not statistically significant.

5. Results and discussion

The focus of this study is on pharmaceutical wholesale companies, which play a crucial role in ensuring the continuous availability of medicines and pharmaceutical products to healthcare institutions, pharmacies, and ultimately patients. The sample comprises 123 micro and small companies and 34 medium and large companies operating in the Croatian pharmaceutical wholesale sector.

The descriptive statistics reveal several notable differences between the two company-size groups. Medium and large companies exhibit longer average accounts receivable collection period (123.08 days) compared with micro and small companies (90.61 days). One possible explanation is that larger wholesalers operate more extensive distribution networks and maintain business relationships with a broader range of healthcare institutions and pharmacies, which may result in longer collection periods. In contrast, micro and small companies display considerably longer inventory holding periods (202.90 days compared with 79.10 days) and longer payment periods to suppliers (94.62 days compared with 70.00 days). These findings suggest less efficient working capital management and a stronger reliance on trade credit among smaller companies. The average return on assets is very similar across the two groups (13.43% for micro and small companies and 13.31% for medium and large companies); however, micro and small companies exhibit substantially greater variability, indicating higher financial instability and more challenging business conditions.

The correlation analysis indicates that profitability is negatively associated with all three working capital management indicators. The strongest negative correlation is observed between ROA and inventory holding periods (DIS), suggesting that longer inventory cycles may be particularly detrimental to profitability. Since these correlations are based on pooled panel data, they should be interpreted with caution and viewed as preliminary evidence rather than causal relationships. The fixed-effects panel models indicate that all three working capital management components, days of receivables collection (DCR), days of inventory stocked (DIS), and days of payment to suppliers (DPS), have a negative and statistically significant effect on profitability. These findings are generally consistent with the prevailing empirical literature, which reports that longer working capital cycles tend to reduce profitability by tying up financial resources and increasing operating costs.

The negative effect of DCR is consistent with numerous previous studies, including Gill et al. (2010), Akoto et al. (2013), and Pais and Gama (2015), which report that longer receivables collection periods reduce profitability because financial resources remain tied up in outstanding receivables and cannot be used for productive investments. Similarly, the negative effect of DIS supports findings reported by Sen and Oruc (2009), Enqvist et al. (2014), and Seyoum et al. (2016), suggesting that prolonged inventory holding periods increase storage, handling, and obsolescence costs, thereby reducing profitability.

The results also indicate a negative relationship between DPS and profitability. This finding is consistent with studies such as Pais and Gama (2015), Enqvist et al. (2014), and Seyoum et al. (2016), which argue that prolonged payment periods may reflect liquidity constraints or financial difficulties. However, the analysis further reveals that company size significantly moderates this relationship. While DPS has a negative effect on profitability among micro and small companies, the effect becomes positive for medium and large companies. This suggests that larger companies may be better positioned to use supplier credit strategically and exploit their stronger bargaining power, which is more consistent with the findings of Mathuva (2010) and Gul et al. (2013).

The COVID-19 variable exhibits a negative and statistically significant coefficient across both FE and CCEMG specifications, indicating that the pandemic adversely affected profitability in the pharmaceutical wholesale sector. This finding is consistent with Shen et al. (2021), who documented a negative impact of the pandemic on company performance, as well as with Hamshari et al. (2022) and Yousaf (2022), who reported significant disruptions in working capital management during the COVID-19 period. The results also support the conclusions of Liu et al. (2024), who found that the relationship between working capital management and financial performance became more pronounced during the COVID-19 crisis. Inflation likewise exerts a negative effect on profitability, highlighting the importance of macroeconomic conditions for company performance.

The diagnostic tests reveal the presence of serial correlation, cross-sectional dependence, and slope heterogeneity, indicating that the assumptions underlying the standard fixed-effects estimator are not fully satisfied. Consequently, the Common Correlated Effects Mean Group (CCEMG) estimator was employed to obtain more robust estimates. Although the CCEMG results are weaker in terms of the number of statistically significant coefficients, several important findings remain consistent across both estimation approaches. First, DPS remains a statistically significant determinant of profitability. Second, the negative impact of the COVID-19 pandemic is confirmed in both methodologies. Third, the interaction between DPS and company size remains positive and statistically significant, indicating that the moderating role of company size is robust across alternative specifications. Finally, inflation continues to exert a negative effect on profitability. At the same time, the CCEMG results suggest that the effects of DCR and DIS become less robust once cross-sectional dependence and heterogeneous slopes are explicitly considered. This finding highlights the importance of accounting for common macroeconomic shocks and unobserved factors that simultaneously affect companies operating within the same sector.

Overall, the results provide only partial support for the proposed hypothesis. The moderating role of company size is consistently confirmed for DPS across both FE and CCEMG estimators, whereas the interaction effects involving DCR and DIS are generally not statistically significant. Therefore, differences between company-size groups appear to be concentrated primarily in supplier payment management rather than across all components of working capital management.

From a managerial perspective, the findings underline the importance of efficient working capital management, particularly during periods of economic uncertainty. The significant negative effects of both COVID-19 and inflation demonstrate that crisis conditions may substantially affect profitability. In such circumstances, maintaining liquidity becomes a strategic priority. Companies should continuously monitor receivables, inventories, and payables and adjust their working capital policies to changing market conditions to preserve financial stability and operational continuity. In crisis conditions, the principle that *cash is king* becomes particularly relevant, meaning that cash flow becomes the most important resource. In such circumstances, companies are often required to establish a so-called *cash room* (or cash management task force), where the primary objective is the stabilization of cash flow—accelerating cash inflows, reducing cash outflows, and increasing liquidity. Once liquidity is stabilized, the second phase follows, involving changes in policies aimed at long-term adjustment to crisis conditions.

6. Conclusion

This study examined the relationship between working capital management and profitability in Croatian pharmaceutical wholesale companies during the period 2015–2024. The study also developed and applied a panel-data framework for analysing the impact of working capital management on profitability while accounting for company size and selected macroeconomic factors.

The results provide partial support for the proposed hypothesis. The findings indicate that the effect of working capital management on profitability differs across company-size groups primarily through the days of payment to suppliers (DPS) component. While DPS negatively affects profitability among micro and small companies, the effect becomes positive for medium and large companies. In contrast, the moderating effects of company size on DCR and DIS are generally not statistically significant across model specifications. The results further demonstrate that longer receivables collection periods, inventory holding periods, and supplier payment periods are generally associated with lower profitability. In addition, both the COVID-19 pandemic and inflation exerted statistically significant negative effects on profitability.

The baseline analysis was conducted using fixed-effects panel models, while additional robustness was provided through the application of the Common Correlated Effects Mean Group (CCEMG) estimator. Although some coefficients became less significant under CCEMG estimation, the negative impact of COVID-19, the negative effect of inflation, and the positive moderating role of company size in the DPS-profitability relationship remained consistent. These findings suggest that the main conclusions are robust to cross-sectional dependence and slope heterogeneity.

The findings provide useful guidance for managers operating in pharmaceutical wholesale companies. Efficient working capital management remains essential for maintaining profitability, particularly during periods of economic instability.

Managers should pay special attention to receivables collection, inventory control, and supplier payment policies, while also considering the specific characteristics associated with company size. The results suggest that larger companies may be able to utilise supplier credit more effectively, whereas smaller companies should exercise greater caution when extending payment periods.

Several limitations of this study should be acknowledged. Although the model includes relevant macroeconomic controls, other company-level determinants of profitability identified in previous research, such as financial leverage, investment activity, sales growth, liquidity indicators, and other financial characteristics, were not included. Future research could incorporate these variables to provide a more comprehensive explanation of profitability.

Future studies could also examine the cash conversion cycle (CCC) as a composite measure of working capital management and investigate potential non-linear relationships between working capital management and profitability. Furthermore, future research could extend the analysis beyond the pharmaceutical wholesale sector itself and examine how the efficiency of pharmaceutical distribution influences the broader healthcare system.

Attention should also be devoted to inventory management practices in pharmaceutical supply chains, given the importance of ensuring the continuous availability of medicines. Unlike many other wholesale sectors, pharmaceutical wholesalers operate in an environment where inventory shortages may have serious consequences for public health. Consequently, future research could explore optimal inventory management models capable of balancing cost efficiency with supply reliability and healthcare system needs.

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Učinci upravljanja obrtnim kapitalom na profitabilnost veleprodajnih farmaceutskih poduzeća u Hrvatskoj

Darija Prša[1]

Sažetak

Glavni cilj ovog rada je ispitati odnos između upravljanja obrtnim kapitalom i profitabilnosti poduzeća koja se bave veleprodajom farmaceutskih proizvoda za ljekarne, bolnice i druge zdravstvene ustanove u Hrvatskoj. Ovaj cilj proizlazi iz istraživačkog pitanja ima li upravljanje obrtnim kapitalom jednak učinak na profitabilnost mikro i malih poduzeća u odnosu na srednja i velika poduzeća. Na temelju uzorka od 157 poduzeća promatranih u razdoblju od 2015. do 2024. godine, provedena je analiza panel podataka kako bi se ispitao utjecaj, intenzitet i smjer ključnih čimbenika upravljanja obrtnim kapitalom, kao što su dani naplate potraživanja (DNP), dani vezivanja zaliha (DVZ), i dani plaćanja obveza prema dobavljačima (DPD), na profitabilnost mjerenu povratom na imovinu (ROA). Rezultati pokazuju da DNP, DVZ i DPD imaju negativne učinke na ROA, pri čemu je učinak DPD-a najkonzistentniji. Pandemija COVID-19 i inflacija dodatno su smanjile ROA. Važno je napomenuti da veličina poduzeća moderira učinak DPD-a, pri čemu učinak ostaje negativan za mikro i mala poduzeća, a postaje pozitivan za srednja i velika poduzeća. Podaci su prikupljeni iz Registra godišnjih financijskih izvještaja FINA-e, dok su podaci o BDP-u i inflaciji preuzeti s internetskih stranica Državnog zavoda za statistiku.

Ključne riječi: *veleprodaja, farmaceutski proizvodi, obrtni kapital, profitabilnost, Covid-19*

JEL klasifikacija: *G30, G32, G39*

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Determinants of Supply Chain Performance in Croatian Dental Care: A Factor-Based Analysis*

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Abstract

The swift advancement of medical knowledge and technologies in dentistry has transformed the aesthetics and robustness of this sector in numerous ways. Consequently, supply chains have become increasingly complex, with a growing number of factors affecting their efficiency. The main goal of this paper is to determine the individual impact of supply chain management (SCM) factors on supply chain performance in the dental industry of the Republic of Croatia. This research examines the connection between several SCM factors (technology, digitalization of processes, information technology, partner relationships, availability of financing sources and value creation) and supply chain performance factors. Multiple regression analysis was used to test the hypotheses of the research model, while exploratory factor analysis was used to test the validity and reliability of the research variables. The findings indicate that technology and partner relationships among supply chain participants have a strong and positive influence on supply chain performance. In addition, value creation and information technology show only a partially positive influence on supply chain performance. The study also confirms that the availability of funding sources and the digitalization of processes do not have a strong positive impact on supply chain performance.

Keywords: *dental industry, supply chain management, SCM factors*

JEL classification: *M10, I10, L22*

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1. Introduction

Until recently, dental service providers were predominantly small private or public practices primarily focused on the repair and extraction of teeth and restricted dental structures. Their supply chains, spanning patient intake, x-rays, material procurement, and ultimate service, were procedurally fractured and loosely coordinated. Today, however, dental industry has undergone substantial transformation, mainly due to rapid advances in medical technology and the need to improve efficiency. Larger entities capable of investing in advanced technologies, streamlining processes and leveraging economies of scale are increasingly dominating the market. These groups operate more efficiently, reduce operating costs and increase their market share (Wall & Guay, 2015). For instance, technology and digitalization play a central role in improving the performance of dental practices, while strategic mergers enable these larger groups to further optimize their supply chains and service delivery.

Small dental practices that traditionally offered basic services, such as extractions and fillings, are now struggling with increased operating costs and a growing demand for a wider range of services (Cooper, 2017). As a result, many independent practices are either closing or merging with larger *managed group* practices. Data show that independent practices are shrinking by approximately 7% annually, while managed dental groups are growing by around 20% annually (Cooper, 2017). The underlying assumption is that strategic alliances can generate certain benefits, such as improved supply chain performance, ultimately enhancing end consumer satisfaction (Porter, 1998). These benefits are believed to arise from the implementation of supply chain management (SCM) (Horvath, 2001; Mentzer, 2004), which shape supply chain processes more effectively than the natural processes that occur in the absence of structured SCM.

This research acknowledges that the use of the SCM concept, particularly the factors influencing SCM within dental businesses, has not yet been adequately explored. Therefore, the primary aim of this study is to identify SCM factors that positively contribute to supply chain performance in the Croatian dental industry. In this context, the study examines the relationship between six SCM factors (value creation, technology, information technology, digitalization of processes, partner relationships, and availability of funding sources) and supply chain performance. This study builds on the doctoral thesis of Pezo (2023).

The research significantly contributes to the domain of SCM within the dental industry, as the impact of individual SCM factors on supply chain performance has not been previously examined. Statistical analysis confirms a strong and positive impact of technology and relationship among participants on supply chain performance, whereas information technology and value creation contribute only slightly. The availability of funding sources and the digitalization of processes do not significantly affect supply chain performance. Despite growing recognition of SCM's importance in healthcare delivery, substantial gaps remain in understanding SCM dynamics within the dental industry. Recent literature largely focuses on general healthcare supply chains (Apeh et al., 2024), with limited attention to the specific characteristics of dental service delivery and product supply networks. Whilst emerging technologies such as blockchain (Ingle et al., 2023) and additive manufacturing (Bhargav et al., 2018) have attracted scholarly interest, these studies remain mostly conceptual, lacking empirical validation of their impact on dental supply chain performance.

A critical gap exists in empirical research examining the relationships between specific SCM factors and performance outcomes in dental contexts. Existing research predominantly adopts theoretical or review-based methodologies (Hassani et al., 2021), with few studies providing quantitative evidence on how technology adoption, partner relationships, digitalization, and information systems influence operational performance in dental practices. A notable exception is research conducted by Başal and Sarkbay (2023), who examined lean supply chain strategies in Turkish dental hospitals. However, their study focuses primarily on consumer behavior, rather than a comprehensive analysis of SCM factors. This study addresses this gap by empirically testing the relationships between six key SCM factors (value creation, digitalization of processes, information technology, partner relationships, technology, and funding availability) and supply chain performance using multiple regression analysis of data from the Croatian dental industry.

Although digital transformation discourse dominates contemporary SCM literature (Singh & Rawat, 2024), the specific impact of digitalization on dental supply chains remains underexplored. Studies examining digital workflows in dentistry (Alberto et al., 2023) primarily concentrate on clinical applications rather than supply chain implications. Regional disparities in SCM implementation underscore the need for context-specific research; existing research provides limited insight into the operational dynamics of dental supply chains within particular national settings, outside overarching sustainability paradigms. This study contributes empirical evidence from Croatia, enriching the understanding of regional SCM dynamics. Nonetheless, significant opportunities remain for future research, including cross-national comparative studies, longitudinal analyses of digital transformation impacts, the development of comprehensive performance measurement frameworks integrating financial and non-financial metrics, and investigation of supply chain resilience factors in dental tourism and international procurement networks.

This paper comprises six sections. The first section outlines the concept of SCM and reviews previous studies on supply chains in the dentistry sector. The second section presents the theoretical foundations of incorporating SCM elements into complex business systems. This section is subdivided into seven subsections looking closely at SCM factors and supply chain performance. The third section introduces the research model and hypotheses, whereas the fourth section describes the research methodology, including the questionnaire design, the pilot study and data collection. The research results and discussions are interpreted in the fifth section, while the conclusion is presented in the sixth section.

2. Literature review

Supply chains and SCM, in the modern sense of the term, did not gain prominence during the period when dentistry was practiced almost exclusively by small, individual, easily managed firms. However, rapid advancements in implantology and dental technologies have increased the importance of small dental firms (Boogaard et al., 2017; Poirier & Walker, 2005) and have encouraged their strategic integration into more complex supply chains (Guay & Wall, 2016). This shift has elevated the relevance of SCM as a means of improving both business and supply chain performance (Hsu et al., 2009). Accordingly, this study investigates how strategic dental supply chains are managed to enhance supply chain effectiveness. In this regard, the study highlights the function and significance of SCM in dental industry as a fundamental idea that facilitates the alignment and balancing of the diverse business objectives across supply chain participants (Guay & Wall, 2016).

The effectiveness of the dental supply chain largely depends on how it is managed. Consequently, SCM is essential for achieving efficiency and effectiveness across the entire chain. This raises the question of how SCM can be improved and which factors must be implemented to optimize its functionality on both sides of the supply chain. SCM factors have demonstrated a beneficial influence on the efficiency and efficacy of various supply chains, such as wood processing, automotive manufacturing, food production, and textile industries. Identifying these factors within the dental sector is equally important. Drawing on the experiences of other SCM researchers and practitioners in the dental industry, this paper identifies the following SCM factors: value creation, technology, information technology, digitalization of processes, relationships between supply chain participants, availability of financing sources and supply chain performances. These key factors of SCM are discussed in more detail below.

2.1. Value creation

The concept of value creation (Li, 2002; Samaržija, 2014) refers to activities that create value throughout the supply chain, benefiting all participating companies. Despite its relevance, research on value creation remains fragmented (Mukhtar & Azhar, 2020), reflecting the concept's complexity and ambiguity. The challenge lies in the fact that value is a socially constructed concept that is evaluated differently in different contexts.

There are two predominant frameworks which explain value creation: production theory, which focuses on value from a managerial perspective, and exchange theory, which focuses on value delivered to the customer. From a managerial standpoint, value creation is linked to quality integration within the supply chain, which enhances customer satisfaction and business performance. As an upgrade of the internal quality management systems, supply chain quality management (SCQM) ensures that consistent quality standards are implemented by all members. Implementing SCQM enables organizations to streamline processes, reduce costs, and improve overall efficiency (Ionel, 2024). In contrast, the marketing perspective views value as customer-centric and highlights the importance of customization. The customization of products and services in order to meet specific customer needs is becoming increasingly important in industries such as e-commerce, agriculture and manufacturing, leading to higher satisfaction and competitive advantage (Tian, 2023). Customization actively involves consumers and enhances consumer engagement and satisfaction.

2.2. Digitalization of processes

By enhancing the agility of information systems, digitalization can shorten information-processing cycles, strengthen environmental sensing, and improve rapid-response capabilities. It has therefore become a critical pathway and an urgent requirement for achieving decision optimization in supply chains (Ma & Kang, 2025). By utilizing state-of-the-art technologies such as the Internet of things (IoT), data analytics, and artificial intelligence, supply chain process digitization significantly improves operational efficiency and reduces costs. Supply chains become more resilient and agile as a result of leveraging these technologies, which enhance visibility, cooperation, and decision-making. Unlike information technology, digitalization refers to the process of transforming corporate operations using cutting-edge technologies to improve supply chain effectiveness and efficiency.

Digitalization transforms traditional processes into automated, data-driven workflows that facilitate real-time decision-making and improve responsiveness to customers. Furthermore, it enhances inventory visibility, improves demand accuracy, and increases overall performance. In traditional businesses, digital technologies optimize inventory control, reduce stockouts, and enhance customer satisfaction through faster order processing and delivery (Singh & Rawat, 2024).

Despite its benefits, digitalization also presents challenges that organizations inside the supply chain must navigate. Factors such as external uncertainties and organizational readiness can influence the effectiveness of digital transformation efforts. Therefore, a strategic approach that considers these complexities is essential for organizations to harness the full potential of digitalization and sustain enhanced performance.

2.3. Technology

Work processes in many industries, especially in medicine, are constantly evolving. Advances in work equipment enable the creation of more functional, higher-quality and cost-effective products, while also improving services. In this sense, technological development creates a competitive advantage for companies and their supply chains.

In the context of this paper, the term *technology* refers to the means of production which deliver products or services to consumers, such as CAM / CAD technologies and digital imaging tools. Intraoral scanners and CAM / CAD technologies have completely reshaped the creation of dental restorations, allowing for precise and efficient design and production. These technologies reduce chairside time and improve the fit and function of prosthetics, resulting in better treatment outcomes (Dhillon, 2024). Similarly, 3D imaging technologies provide detailed visualizations of the oral cavity, aiding in accurate treatment planning and diagnosis. These tools enable the creation of virtual patient models, which are instrumental in surgical planning and the development of patient-specific treatments (Zimmermann & Seitz, 2023).

Variations in technology adopted by different members of a supply chain can lead to differing degrees of value creation and customer satisfaction, even within the same industry.

Technological progress (Martinelli & Tunisini, 2019; Samaržija, 2014) has made it possible, for instance, to perform restorative procedures, such as the replacement of missing teeth, that were previously unimaginable. Advancements in technology are significantly transforming dental medicine, enhancing diagnostic accuracy, treatment planning, and overall patient care. These innovations, ranging from artificial intelligence (AI) to digital imaging and 3D printing, are reshaping the landscape of dentistry by improving precision, efficiency, and patient engagement. The integration of these technologies not only streamlines clinical workflows but also supports a more patient-centric approach to oral healthcare.

2.4. Information technology

Collaboration in supply chains is built on the efficient exchange of key information. A robust information system strengthens this collaboration by enabling faster and more accurate communication between partners. Progressive supply chains must continuously train their employees in emerging technologies and employ strategies that support timely modernization. Integrating information technology into SCM (Tadepalli, 2014) improves production control, inventory management and collaboration between partners, while also optimizing order and shipment tracking. Modern software and digital tools provide real-time insights into the production process, enabling companies to anticipate potential problems and adapt accordingly. Improved inventory management, supported by enterprise information systems, reduces costs across the supply chain (Evangelista & Hallikas, 2022).

Today, information technology is changing business processes and the dynamics between supply chain participants (Scuotto et al., 2017) and transforming dental supply chains (Klingenburg, 2016) by leveraging digitalization, cloud technologies, artificial intelligence (AI) and user-friendly platforms. These innovations blur traditional organizational boundaries and enhance supply chain efficiency and resilience. Many industries, including manufacturing, healthcare, and logistics, now require AI systems capable of extending their intelligence into the physical world and interacting directly with objects, environments, and dynamic conditions (Bousetouane, 2025).

2.5. Partner relationships

Relationships between supply chain participants are essential for overall performance. The selection of partners and suppliers is crucial for delivering services that meet user expectations. Powerful relationships are based on mutual respect, trust and shared goals not only to improve SCM, but also to enhance performance (Li, 2002). Research confirms a positive correlation between the quality of these relationships and supply chain outcomes (Guay & Wall, 2016; Handfield & Nichols, 2002; Langelier et al., 2017).

Trust and a shared vision are key elements that foster collaboration and operational efficiency. A shared vision strengthens collaboration, aligns goals and improves communication between partners, which increases supply chain efficiency (Yang & Huang, 2018). It promotes transparency, reduces conflict and improves overall reliability. This alignment leads to improved operational performance, cost reductions and innovation. Partner responsibility ensures compliance with social, environmental and ethical standards (Han & Yuan, 2019). Mutual commitments promote win-win outcomes and ensure balanced profitability for all parties by promoting socially responsible practices without compromising business objectives. Trust is the foundation for supply chain relationships as it fosters collaboration and reduces risk (Cooper, 2024). Effective communication, cultural alignment and ethical practices are critical for building trust, which in turn strengthens supply chain resilience and competitiveness.

2.6. Availability of funding sources

Supply chain finance focuses on core enterprises, manages the capital flow, logistics and information flow of upstream and downstream small and medium-sized enterprises, and transforms the uncontrollable risks of individual firms into the controllable risks of the supply chain enterprise (Liu et al., 2024). The intensity of this process depends on the financial investment opportunities of the members of the supply chain (Achermann, 2012). Efficient financial management in the supply chain is, therefore, a strategic priority of the company, requiring continuous investment to ensure supply chain efficiency and competitiveness. The sources of financing can be the company's own funds, but more often they are bank loans (Shen et al., 2020). As a result, supply chains evolve depending on the financial capabilities of their participants, but also on the possibilities of securing various sources of financing (Samaržija, 2014).

The default of one or more members significantly increases financial risk, which has a detrimental impact on the entire supply chain. Studies show (Caniato et al., 2016) that, on average, a quarter of the shock caused by a default in the supply chain is passed on to other members, and this process is stopped only once payment is made. In this context, a decrease in the availability of borrowing capacity increases the risk of non-payment or payment delays in the supply chain (Coricelli & Masten, 2004). Consequently, financial risk management must be recognized as an integral part of SCM and should find its place and importance across SCM (Raddatz, 2010). This study, therefore, investigates whether supply chain participants face difficulties in securing financing and whether they have access to favorable sources of financing to support operations within the supply chain.

2.7. Supply chain management performance

Supply chain performance is a complex, multifaceted concept that differs across industries and requires customized indicators that reflect the unique challenges of each industry. Effective performance indicators must cover all critical dimensions of the supply chain. Integration between partners is crucial for seamless operations and thus a key indicator of supply chain result (Flynn et al., 2010). Furthermore, the capability to adapt to internal and external changes is crucial in order to respond quickly to new products and market demands (Soon & Udin, 2011). Meeting customer needs promptly and providing quick feedback are essential elements of responsiveness, depending heavily on supplier and partner performance to ensure reliable, on-time delivery (Duclos et al., 2003).

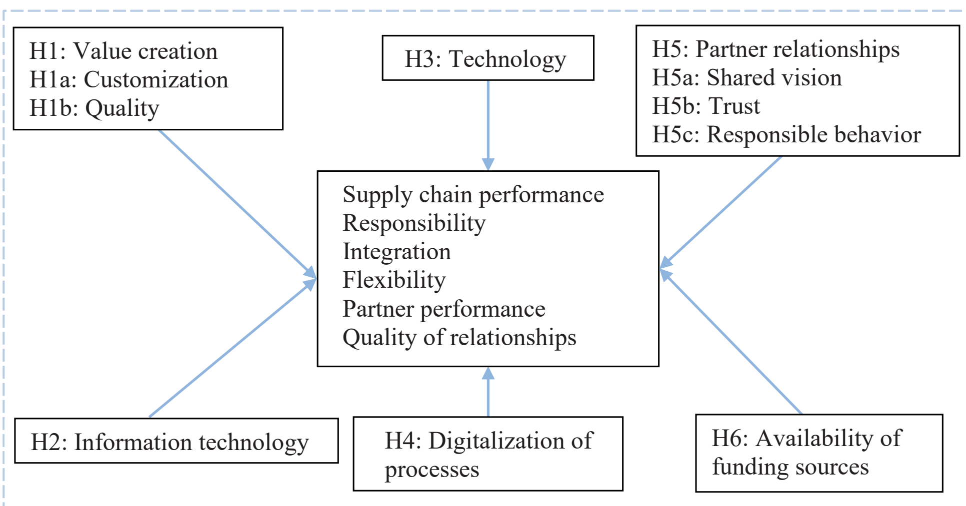
Li (2002) identifies five key indicators for evaluating supply chain performance: flexibility, integration, responsiveness, partner performance and relationship quality. Flexibility enables supply chains to adapt to market fluctuations and uncertainties, which is critical for maintaining a competitive advantage in a dynamic environment. Integration refers to seamless coordination between stakeholders, improving efficiency and reducing costs. Responsiveness measures the capability of a supply chain to adjust quickly to change and maintain customer satisfaction. Partner performance assesses the reliability of partners and their alignment with strategic objectives to ensure operational efficiency. Relationship quality is about trust, commitment and collaboration, which are essential for strong partnerships and long-term success.

The relevance of this research lies in the increasing competition among dental service providers (Mazzei et al., 2009) and the limited empirical investigation of SCM factors and their impact on performance within the dental industry (Deshpande, 2012).

3. Research model and hypotheses

The research model used to determine the relationship between six SCM factors: availability of funding sources, partner relationships, value creation, digitalization of processes, information technology, and supply chain performance is presented in Figure 1. Additionally, Figure 1 illustrates the relationship between the dependent variable (supply chain performance) and the independent factors (value creation, information technology, technology, digitalization of processes, availability of funding sources, and partner relationships).

Figure 1: Research model



Source: Author’s illustration

Research Hypothesis 1 (Value creation and SCM performance)

According to Bowersox et al. (2010), value creation has a strong positive impact on supply chain performance by increasing market share, enabling product customization and achieving economies of scale. This study examines the connection between the value-creation process and supply chain performance in the dental industry. Considering that the dental industry is characterized by a process-oriented supply chain where raw materials are transformed into final products, this hypothesis aims to determine the strength of the link in supply chains in the dental industry.

To obtain accurate results, the individual contributions of customization and process quality to supply chain performance factors are also tested. Based on this rationale, the hypotheses of the model are:

H1: *Value creation contributes significantly to SCM performance.*

H1a: *Customization contributes significantly to SCM performance*.

H1b: *Quality contributes significantly to SCM performance.*

Research Hypothesis 2 (Information technology and SCM performance)

The strong positive relationship between information technology and supply chain performance has been demonstrated several times in prior research (Chen & Paulraj, 2004a). The present research aims to examine this relationship in the dental industry, focusing on both small and large clinics as integral parts of complex business systems. Since the functioning of any modern supply chain is impossible without information technology, its presence is not in question. What remains to be assessed is the extent of its impact on specific factors of supply chain performance.

H2: *Information technology contributes significantly to SCM performance.*

Research Hypothesis 3 (Technology and SCM performance)

Technology has radically changed the dental sector and enhanced the performance of the entire supply chain. Given the multiple players involved in dental supply chains, the introduction of advanced technological solutions, such as artificial intelligence, digital impressions and 3D printing, can significantly improve supply chain performance. Research shows that the integration of progressive technologies not only streamlines operations but also increases efficiency and has a strong positive impact on overall performance (Chen & Paulraj, 2004b). The third hypothesis therefore examines how technology affects different supply chain performance indicators:

H3: *Technology contributes significantly to SCM performance.*

Research Hypothesis 4 (Digitalization and SCM performance)

Over the past decade, business processes in the dental industry have become highly digitized, transforming nearly every aspect of the value chain, including patient diagnosis, prosthetic design, surgical planning and execution, and data sharing and archiving. Digitalization has streamlined operations, increased service quality and improved information flow to ensure compliance with various administrative requirements (e.g. GDPR). Therefore, the fourth hypothesis of the model is:

H4: *Digitalization contributes significantly to SCM performance.*

Research Hypothesis 5 (Partner relationships and SCM performance)

Since a supply chain is a system of interdependent organizations by nature, meeting customer needs requires that all participants, suppliers and customers work toward the same business objectives. For this reason, partner relationships form the backbone of effective SCM (Burgess, 1998). This implies that in order to effectively provide the final service, suppliers and consumers within the supply chain must be systematically interconnected in the dental industry. Meeting long-term customer needs also depends on creating a common vision with the other supply chain participants.

As partner relationships are crucial for the success of the supply chain, mutual trust among members is also required. The operational functioning of the supply chain involves numerous daily transactions between members, and for long-term sustainability of the chain, members must behave responsibly towards each other. In order to accurately determine the connection between partner relations and SCM performance, the following hypotheses are proposed:

H5: *Partner relationships contribute significantly to SCM performance.*

H5a: *Shared vision contributes significantly to SCM performance.*

H5b: *Trust contributes significantly to SCM performance*.

H5c: *Responsible behavior contributes significantly to SCM performance.*

Research Hypothesis 6 (Availability of funding sources and SCM performance)

Financing plays a critical role in enhancing supply chain performance. Its impact is multifaceted; it can be used to finance new technologies that lead to greater flexibility and/or integration between supply chain members. It is also possible to finance different parts of the supply chain to improve different business metrics. Therefore, the sixth hypothesis is:

H6: *Availability of funding sources contributes significantly to supply chain performance.*

In summary, the proposed model aims to identify the individual contribution of each SCM factor in order to determine the intensity of their implementation and the impact they have on the supply chain performance.

4. Research design and methods

This chapter outlines the design of the survey instrument, the data collection procedure, and the analytical method used in the study.

4.1. Survey instrument design

A questionnaire was employed as the primary research tool for the empirical investigation. Taking into account the objectives of the study and the specificity of the required data, it was essential to collect detailed information on work processes in different dental organizations. Accordingly, the questionnaire was designed for completion by managers from various dental organizations.

The questionnaire consisted of three sets of questions. The first set of questions focused on constructs related to value creation, technology, information technology, digital process design, partner relationships, and the availability of funding sources. These constructs were considered as key SCM factors. The second set of questions addressed the construct of SCM performance, capturing the effectiveness of supply chain implementation through indicators such as the degree of flexibility, integration, responsiveness, partner performance and quality of relationships. The third set of questions collected socio-demographic information about respondents, including age, overall work experience, gender, education level, work experience in the current organization, and the respondent's position within the observed organization. This set also included questions about the characteristics of the dental organization under study, including the number of employees and the organizational structure.

The degree of agreement with particular statements was assessed using a 5-point Likert scale (1 to 5), where 1 represented *strongly disagree*, 2 represented *somewhat disagree*, 3 represented *neither agree nor disagree*, 4 represented *somewhat agree*, and 5 represented *strongly agree*.

To ensure the validity and reliability of the questionnaire, analyses were conducted both before and after data collection. First, all English statements were translated into Croatian and then back-translated into English to ensure linguistic accuracy. Second, a pilot study involving five professionals was conducted to identify and correct ambiguities in wording and terminology. This pilot study was carried out in the first half of February 2021, and out of the five professionals, three experts were engaged in a scientific study on dental supply chain phenomena, and two experts were managers of dental organizations.

4.2. Data and analytical methods

The survey was conducted from March 1, 2021 to January 31, 2022. Owners, directors, clinic managers and/or managers of the largest dental organizations in the Republic of Croatia were contacted, as they, as top management, have the best insight into all supply chain processes and can accurately evaluate the variables analyzed at the organizational level. The research sample included all dental organizations in Croatia.

A purposive sampling method was employed, allowing for available individuals who are also experts in their field to be included. Owners, directors, clinic managers and/or managers of the largest dental organizations in Croatia were contacted to answer questions about the supply chain in which their organizations are involved. Ultimately, the sample included 102 dental clinics/organizations in the Republic of Croatia. Table 1 provides the descriptive characteristics of the sample.

Table 1: The sample's descriptive characteristics

Characteristic	Number	Share (percentage)
Education		
Secondary education	2	1.96
Undergraduate education	2	1.96
Graduate education	69	67.65
Postgraduate education	29	28.43
Gender		
Male	56	54.90
Female	46	45.10
Number of permanent employees		
1-4	49	48.04
5-9	19	18.63
10-19	7	6.86
20-59	16	15.69
50-100	2	1.96
100 +	9	8.82
Change in the number of users		
Increased	67	65.69
Stagnant	22	21.57
Decreased	13	12.75

Source: Author's calculations

The majority of respondents holds a higher education degree (67.65%) and are male (54.90%). Experience in the current role ranges from 1 to 32 years, with an average of 12 years ($\bar{x}$=11.92), whereas overall work experience ranges from 1 to 50 years, with an average of 19 years ($\bar{x}$ =19.19). The average respondent age is 45 years ($\bar{x}$ = 45.19), with a range of 25 to 74 years.

Regarding the size of the organization, measured by the number of employees, the sample mainly includes organizations with a small number of employees: 1 to 4 employees (48.04%), or 5 to 9 employees (18.63%). Dental organizations with 20 to 59 employees make up 15.69% of the sample. For most dental organizations, the number of users has increased (65.69%), while 12.75% report a decrease in users compared to 2019. The majority of respondents are team leaders (32.4%), followed by directors (8.8%), owners (7.8%), managers (4.9%) and other managerial roles (2%). The remaining respondents did not specify their role in the dental organization.

Data were analyzed using exploratory factor analysis (EFA) to identify factor structures, followed by the creation of summated scales by calculating the arithmetic means of the respective items. Multiple linear regression based on the ordinary least squares (OLS) method was then conducted using the Enter procedure, with all independent variables entered simultaneously. Five separate regression models were estimated, each with a different dimension of supply chain performance (flexibility, integration, responsiveness, partner performance, and relationship quality) as the dependent variable. Assumptions of OLS regression were tested prior to analysis. All analyses were performed using the SPSS program.

5. Research results and discussion

To test the hypotheses, summated scales were created for the individual constructs used in the study. These summated scales were derived from items (statements) that were loaded onto specific factors following exploratory factor analyses. The arithmetic mean of the items contained for each factor was used to calculate the scales. A multiple regression analysis was conducted using supply chain performance (flexibility, integration, responsiveness, partner performance and quality of partner relationships) as dependent variables. The independent variables of the model included process digitalization, technology, information technology, value creation (quality and customization), availability of finance and relationships between stakeholders (trust, shared vision and responsible behavior). The Enter method was utilized to incorporate independent variables into the model for every regression analysis. Next, flexibility, as a SCM performance indicator, was used as the dependent variable in a multiple regression analysis. The model explained 54.8% of the variance in the results. The results of this analysis are presented in Table 2.

Table 2: Results for SCM performance – flexibility

Variable	B	β	t–value
Constant	0.379 (0.619)		0.612
Digitalization of processes	0.073 (0.078)	0.103	0.932
Technology	0.117 (0.142)	0.073	0.822
Information technology	0.091 (0.078)	0.109	1.170
Value creation – quality	-0.040 (0.039)	-0.088	-1.032
Value creation – customization	0.205 (0.075)	0.229	2.729**
Availability of funding sources	-0.071 (-0.071)	-0.101	-1.143
Partner relationships – shared vision	-0.250 (0.103)	-0.234	-2.415**
Partner relationships – responsible behavior	0.201 (0.101)	0.250	1.993**
Partner relationships – trust	0.574 (0.105)	0.531	5.466***
Multiple regression coefficient R^2	0.548 (0.430)		
R2 (corrected)	0.500		
F-value	11.322***		

Note: *** p < 0.001, ** p < 0.05, * p < 0.10; standard error and standard error of the R2 estimate are in brackets.

Source: Author's calculations

Not all examined independent variables had a statistically significant impact on the dependent variable, as can be seen in Table 2. Customization (β=0.229), responsible behavior toward partners (β=0.250), and trust (β=0.531) are the statistically significant beneficial effects on flexibility. On the other hand, shared vision has a statistically significant negative impact (β= -0.234).

A multiple regression analysis was then conducted with supply chain performance, specifically integration, as the dependent variable. This model explained 61.2% of the variance in the results. The results of this analysis are shown in Table 3.

Table 3: Results for SCM performance – integration

Variable	B	β	t–value
Constant	0.222 (0.668)		0.333
Digitalization	0.142 (0.085)	0.172	1.681
Technology	-0.123 (0.153)	-0.066	-0.804
Information technology	0.313 (0.084)	0.323	3.732***
Value creation – quality	-0.013 (0.042)	-0.024	-0.310
Value creation – customization	0.064 (0.081)	0.061	0.788
Availability of funding sources	-0.121 (0.067)	-0.161	-1.817*
Partner relationships – shared vision	-0.012 (0.111)	-0.009	-.104
Partner relationships – responsible behavior	0.398 (0.109)	0.425	3.660***
Partner relationships – trust	0.289 (0.113)	0.230	2.553**
Multiple regression coefficient R^2	0.612 (0.463)		
R2 (corrected)	0.571		
F-value	14.736***		

Note: *** p < 0.001, ** p < 0.05, * p < 0.10; standard error and standard error of the R2 estimate are in brackets.

Source: Author's calculations

As the data in Table 3 demonstrate, not every independent variable under analysis has a statistically strong and positive impact on the dependent variable. Information technology (β=0.323), trust (β=0.230), and responsible behavior (β=0.425) all have statistically positive and significant effects on integration.

Next, a multiple regression analysis was conducted with supply chain performance – specifically responsiveness – as the dependent variable. This model explained 35.7% of the variance in the results. The results of this analysis are outlined in Table 4.

Table 4: Results for SCM performance – responsiveness

Variable	B	β	t–value
Constant	2.191 (0.496)		4.421***
Digitalization	-0.154 (0.063)	-0.323	-2.454**
Technology	0.278 (0.114)	0.260	2.450**
Information technology	0.057 (0.062)	0.101	0.909
Value creation – quality	-0.019 (0.031)	-0.063	-0.622
Value creation – customization	0.123 (0.060)	0.205	2.045**
Availability of funding sources	-0.099 (0.049)	-0.230	-2.008**
Partner relationships – shared vision	-0.023 (0.083)	-0.033	-0.284
Partner relationships – responsible behavior	0.182 (0.081)	0.338	2.258**
Partner relationships – trust	0.182 (0.084)	0.251	2.163**
Multiple regression coefficient R^2	0.357 (0.344)		
R2 (corrected)	0.288		
F-value	5.180***		

Note: ***p<0.001, **p<0.05, *p<0.10; standard error and standard error of the R2 estimate are in brackets.

Source: Author's calculations

The data in Table 4 show that not all analyzed independent variables have a statistically significant influence on the dependent variable. The statistically significant positive effects on supply chain responsiveness include: responsible behavior (β=0.338), technology (β=0.260), trust (β=0.251) and customization (β=0.205). The independent variables of process digitalization (β=-0.323) and availability of financial resources (β=-0.230) have a negative, but statistically significant influence on responsiveness.

Additionally, a multiple regression analysis was performed, with dependent variable SCM performance – partner performance. This model explained 68.3% of the variation in the results. The results of this analysis are presented in Table 5.

Table 5: Results for SCM performance – partner performance

Variable	B	β	t–value
Constant	-0.112 (0.490)		-0.229
Digitalization	-0.039 (0.062)	-0.058	-0.629
Technology	0.422 (0.116)	0.278	3.636***
Information technology	-0.072 (0.062)	-0.092	-1.156
Value creation – quality	-0.064 (0.031)	-0.147	-2.061**
Value creation – customization	0.046 (0.059)	0.054	0.773
Availability of funding sources	-0.111 (0.049)	-0.185	-2.292**
Partner relationships – shared vision	0.099 (0.082)	0.098	1.211
Partner relationships – responsible behavior	-0.026 (0.079)	-0.034	-0.324
Partner relationships – trust	0.704 (0.083)	0.693	8.513***
Multiple regression coefficient R^2	0.683 (0.338)		
R2 (corrected)	0.649		
F-value	19.905***		

Note: *** p < 0.001, ** p < 0.05, * p < 0.10; standard error and standard error of the R2 estimate are in brackets.

Source: Author's calculations

After analyzing the correlations between the variables, it was shown that the relationship with technology (β=0.278) and partner relationship – trust (β=0.693) had a statistically significant positive impact on partner performance. Furthermore, partner performance is negatively but statistically significantly impacted by the availability of financial resources (β=-0.185) and quality (β=-0.147).

Additionally, the dependent variable, SCM performance – quality of relationship, was subjected to a multiple regression analysis. This model explained 51.8% of the variation in the outcomes. The results of this analysis are displayed in Table 6.

Table 6: Results for SCM performance – quality of relationships

Variable	B	β	t–value
Constant	0.478 (0.628)		0.761
Digitalization	0.125 (0.079)	0.180	1.571
Technology	-0.037 (0.149)	-0.023	-0.246
Information technology	-0.056 (0.080)	-0.069	-0.703
Value creation – quality	0.032 (0.040)	0.071	0.808
Value creation – customization	0.096 (0.076)	0.110	1.265
Availability of funding sources	-0.068 (0.062)	-0.108	-1.085
Partner relationships – shared vision	0.179 (0.105)	0.172	1.712
Partner relationships – responsible behavior	0.228 (0.102)	0.291	2.237**
Partner relationships – trust	0.332 (0.106)	0.314	3.126**
Multiple regression coefficient R^2	0.518 (0.434)		
R2 (corrected)	0.466		
F-value	9.913***		

Note: *** $p < 0.001$, ** $p < 0.05$, * $p < 0.10$; standard error and standard error of the R2 estimate are in brackets.

Source: Author's calculations

Not every independent variable tested has a statistically significant impact on the quality of associations, as demonstrated in Table 6. The relationship with partners – trust (β=0.314) and responsible behavior (β=0.291) are accountable for the statistically significant positive influence on relationship quality.

Table 7 provides a summarized overview of the multiple regression analyses between the dependent variables of supply chain performance (flexibility, integration, responsiveness, partner performance and relationship quality) and the independent variables of SCM (digitalization of processes, technology, information technology, value creation, availability of funding sources and relationships with partners). Only those regression coefficients that are statistically significant are displayed.

Table 7: Summarized overview of multiple regression analyses on the variables of supply chain performance

Variable	Flexibility	Integration	Respon-sivity	Partner performance	Relationship quality
	β	β	β	β	β
Digitalization of processes			-0.323**		
Technology			0.260**	0.278***	
Information technology		0.323***			
Value creation – quality				-0.147**	
Value creation – customization	0.229**		0.205**		
Availability of funding sources		-0.161*	-0.230**	-0.185**	
Partner relationships – shared vision	-0.234**				
Partner relationships – responsible behavior	0.250**	0.425***	0.338**		0.291**
Partner Relationships – trust	0.531***	0.230**	0.251**	0.693***	0.314**

Note: *** $p < 0.001$, ** $p < 0.05$, * $p < 0.10$; standard error and standard error of the R2 estimate are in brackets.

Source: Author's calculations

The results of the empirical analysis indicate that the concept of SCM in dentistry comprises the following factors: digitalization of processes, technology, information technology, availability of funding sources and value creation (quality and customization). All factors demonstrated a high level of reliability, ranging from α=0.627 for the availability of funding sources to α=0.906 for process digitalization, confirming their suitability for further analysis.

The construct of partner relationships was found to consist of three dimensions: trust between participants, responsible behavior towards partners and shared vision. These three factors also demonstrated high reliability ranging from α=0.822 for trust between participants to α=0.844 for responsible behavior towards customers, indicating that they are reliable measures of relationship quality among supply chain participants.

Following statistical data processing, the results revealed that quality significantly affects SCM performance, particularly partner performance (β=-0.147). However, this construct was not further examined in the analysis of hypothesis H1, since the regression coefficient, despite being statistically significant, points in the opposite direction of the hypothesis H1. Further research is necessary to determine the reasons for this unexpected result. As for flexibility (β=0.229) and responsible partner behavior (β=0.205), they are significantly impacted by the second factor, customisation. These results corroborate the findings of Esper et al. (2010), who highlight that effective value creation enhances communication and integration among supply chain participants. Similarly, Al-Mudimigh et al. (2004) argue that businesses are increasingly focusing on value creation for all stakeholders. While the process of value creation should aim to reduce activities that do not increase the value of the final product or service, it remains unclear why quality negatively affects SCM performance. One possible explanation is that certain quality certifications contribute to the standardization of processes, thereby increasing pressure on employees, or that the processes of service delivery become too complex, which is why employees can no longer perceive their contribution to value creation. Based on these findings, value creation is found to partially contribute to the SCM performance, which leads to a partial acceptance of H1.

The findings further show that technology significantly affects partner performance (β=0.278) and partnership quality (β=0.260), indicating that technology enhances SCM performance. Dental organizations which implement appropriate technologies strengthen their partnerships and improve overall SCM performance. This is in line with the findings of Patterson et al. (2003), who highlight the role of technology in improving supply chain partner networking. Based on these findings, hypothesis H2 is accepted.

The statistical analysis also revealed that digitalization of processes has a negative impact on the quality of relationships with partners (β=-0.323). As this regression coefficient is statistically significant, but contradicts the expected direction, it was not considered further in the analysis of hypothesis H3. This finding contrasts the results of DHL Customer Solutions & Innovation (2016), who reported a positive correlation between process digitalization and supply chain performance. A plausible explanation is that lower digital literacy among certain employees in dental organizations may lead to resistance to the implementation of process digitalization, complicating short-term processes despite long-term benefits. Consequently, H3 is rejected.

Information technology has a significant impact on supply chain performance integration (β=0.323). This result aligns with the findings of DHL Customer Solutions & Innovation (2016) and Mahamood et al. (2016), who emphasize the positive relationship between information technology and supply chain performance in dental organizations. Thus, information technology contributes positively to supply chain performance, which leads to the acceptance of hypothesis H4.

The results of this study also show that the relationship between participants in supply chain consists of shared vision, responsible behavior towards customers and mutual trust. The analysis showed that shared vision significantly influences flexibility (β=-0.234). However, due to the regression coefficient being negative and contradicting the hypothesis, it was not further considered in the evaluation of H5. Regarding responsible behavior towards partners, it has a significant influence on flexibility (β=0.250), integration (β=0.425), responsiveness (β=0.338) and relationship quality (β=0.291). As for trust between supply chain members, it significantly influences all performance factors, including flexibility (β=0.531), integration (β=0.230), responsiveness (β=0.251), partner performance (β=0.693) and relationship quality (β=0.314). These findings reinforce the conclusions of Langelier et al. (2017) and Guay & Wall (2016), who found that interpersonal relationships between supply chain participants are essential for the overall functioning of the supply chain and influence its performance to deliver services at the level of quality expected by customers. Consequently, it can be concluded that the relationships among supply chain members positively influence the chain's performance, which leads to the acceptance of H5.

The examination of H6 revealed that the availability of funding sources significantly affects supply chain performance, but in a negative direction. Specifically, the availability of funding sources has a significant negative effect on integration (β=-0.161), responsiveness (β=-0.230) and partner performance (β=-0.185). Although the hypothesis was formulated positively, it was rejected due to the direction of the construct which contradicts expectations and is not aligned with previous research. Voinea-Griffin et al. (2010) emphasize that supply chains develop depending on the financial capabilities of the participants. Therefore, an increase in the availability of funding sources should enhance SCM performance. One explanation for this negative effect may be that dental organizations often make substantial initial investments in technology and infrastructure, reducing the need for additional financing in the short term, which has a negative impact on SCM performance. Furthermore, the connection can be insignificant due to the complex system of interrelated factors that mediate between the financial capital and the actual operational efficiency. Although it might be expected that greater access to capital leads to improved performance, financial resources alone do not guarantee more efficient processes; their effectiveness depends on the organization's ability to allocate and align them strategically with its business goals. In situations where firms lack developed managerial competencies or planning systems, additional capital is often used to cover short-term operating costs, rather than to strengthen key supply chain functions, thereby minimizing its potential impact on overall performance.

Overall, the findings presented in this paper indicate that Croatia's private dental sector meets European standards in terms of service quality, professional competence, and the implementation of modern technologies. However, at the macro level, it is still not fully integrated into the corporate dental medicine model that prevails in Western and Northern Europe. The most significant developmental challenges remain the uneven accessibility of care, limited opportunities for financing development projects, and investments in process digitalization. Nevertheless, Croatia's competitive advantages lie in its lower prices and rapid adaptability to market demands. In summary, Croatia's private dental sector demonstrates strong potential for alignment with best European practices. Continued investments in technology, human resource development, and integration with EU health frameworks could allow the country to achieve both organizational and structural maturity comparable to that of the most advanced dental systems in Europe.

6. Conclusion

This research demonstrates that companies in the dental industry collaborate successfully through the concept of SCM. Key SCM factors in dentistry were identified, including SCM performance, relationships among participants, availability of funding sources, technology, information technology, value creation, and process digitalization. Statistical analysis revealed a positive impact of technology and stakeholder relationships on supply chain performance, while information technology and value creation only partially contribute to supply chain performance. Finally, the availability of funding sources and the digitalization of processes were found to have no influence on supply chain performance.

The development of a conceptual model tailored to dental organizations represents the study's methodological contribution. This study can be used as a reference model for future research examining the effects of SCM on the effectiveness of complex business systems, particularly since existing SCM factors in dentistry have not been sufficiently explored. The study also enhances the understanding of SCM factors in dental businesses by comparing business systems of different sizes and incorporating perspectives from multiple dental managers.

Although the study offers important insights into dental SCM, several limitations should be considered when interpreting the results. The first limitation relates to the relatively small sample, which reflects the current state of SCM in the dental industry in the Republic of Croatia. Future research should include a larger number of dental organizations, using a bigger sample, to validate the findings. In-depth interviews are also recommended to evaluate the conceptual model in various dental organization types, given the limited number of specific dental organization types in the current sample.

A second limitation of the study is that it included only Croatian dental organizations. Similar research should be conducted in other countries with comparable organizational structures and legal regulations for dental organizations. In addition, it would be valuable to qualitatively investigate why this study identifies certain negative relationships, although previous studies in other fields show positive correlations between the constructs of value creation (quality), process digitization, and partnership relations, such as a shared vision, with supply chain performance. Shared vision can negatively affect supply chain performance when it leads to excessive standardization and reduced flexibility among partners. When all participants pursue identical goals without considering their diverse business interests and market conditions, the supply chain's ability to adapt quickly and innovate is diminished. Overalignment often benefits larger partners who impose their priorities, reducing the autonomy and motivation of smaller participants. The implementation of a common vision increases coordination and communication demands, which can cause delays, miscommunication, and inefficiencies.

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Analiza ključnih čimbenika upravljanja opskrbnim lancem u dentalnoj industriji u Republici Hrvatskoj

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Sažetak

Brz napredak medicinskog znanja i tehnologija u stomatologiji transformirao je estetiku i otpornost ovog sektora na brojne načine. Kao rezultat toga, opskrbni lanci postaju sve složeniji, a sve veći broj čimbenika utječe na njihovu učinkovitost. Glavni je cilj ovog rada utvrditi pojedinačni utjecaj čimbenika upravljanja opskrbnim lancem na performanse opskrbnog lanca u dentalnoj industriji Republike Hrvatske. Istraživanje ispituje povezanost između čimbenika upravljanja opskrbnim lancem (tehnologija, digitalizacija procesa, informacijska tehnologija, partnerski odnosi, dostupnost izvora financiranja i stvaranje vrijednosti) i čimbenika performansi opskrbnog lanca. Za testiranje hipoteza istraživačkog modela korištena je višestruka regresijska analiza, dok je za provjeru valjanosti i pouzdanosti istraživačkih varijabli korištena eksploratorna faktorska analiza. Utvrđeno je da tehnologija i partnerski odnosi među sudionicima opskrbnog lanca imaju snažan i pozitivan utjecaj na performanse opskrbnog lanca. Također, stvaranje vrijednosti i informacijska tehnologija imaju samo djelomično pozitivan utjecaj na performanse opskrbnog lanca. Nadalje, rezultati ovog istraživanja potvrdili su da dostupnost izvora financiranja i digitalizacija procesa nemaju snažan pozitivan utjecaj na performanse opskrbnog lanca.

Ključne riječi: *dentalna industrija, upravljanje opskrbnim lancem, čimbenici UOL-a*

JEL klasifikacija: *M10, I10, L22*

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The Relationship Between Environmental Performance and Economic Development: Evidence from European Countries*

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Abstract

Building on the fact that without strong efforts to preserve the natural environment and mitigate the consequences of climate change, no development can remain sustainable in the long term, the primary objective of this paper is to investigate the relationship between environmental performance and achieved economic development of selected European countries. For the realization of defined objectives, an innovative (two-stage) research methodology was employed, based on the combined application of cluster analysis and one-way ANOVA. The classification of 38 European countries into distinctive groups, based on the values of three key components of the Environmental Performance Index (EPI) in 2023, was performed using the hierarchical agglomerative clustering procedure. The obtained "optimal" solution, consisting of three clusters, supplemented by the results of the ANOVA-based evaluation of its statistical quality, unequivocally confirms the presence of pronounced disparities among the observed countries in terms of recorded environmental performance. The formed groups with assigned categories (i.e., high, average and low environmental performance) were used as the independent variable in the second stage of the analysis, designed to examine the statistical significance of differences between the average GDP per capita values determined for the three EPI-based clusters of countries. The ANOVA results unequivocally confirm the presence of a positive and statistically significant relationship between achieved economic development and EPI-based environmental

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performance, among the observed European countries in 2023. The obtained research results can provide valuable insights for sustainability policymakers and a better understanding of the nature of the relationship between the economic and environmental performances.

***Keywords**: cluster analysis, one-way ANOVA, environmental performance index, GDP per capita, European countries*

***JEL classification**: C12, C38, E01, O52, Q56*

1. Introduction

The term *sustainable development* denotes a complex and multidimensional concept, which today, in modern economic and business conditions, is simultaneously understood as the ultimate goal, but also as a means to achieve economic progress while minimizing negative effects on the environment and on society as a whole. In other words, "*sustainable development represents the concept of integrated development of the economic, technological, social and cultural dimensions, balanced with the needs of protection and improvement of the natural environment*" (Veselinović et al., 2023, p. 34). Given the undeniable importance of sustainable development for the long-term survival and progress of humanity, it is not surprising that the international academic and professional community has been interested for decades in finding ways and creating conditions for its establishment at all levels of human organization and economic activity.

The key and strongest stimulus to global efforts aimed at achieving sustainable development was made in September 2015, when the United Nations Assembly adopted the Resolution on Sustainable Development, entitled *The 2030 Agenda for Sustainable Development*, which includes 17 main sustainable development goals (SDGs) and 169 specific goals (Eurostat, 2017). It is necessary to point out that a significant number of SDGs are directly related to the ecological aspects of development, that is, the promotion of a positive environmental impact while achieving economic growth and social progress. Moreover, in parallel with the definition of SDGs, and as part of efforts aimed at achieving them, the need for improving existing and developing new methods for quantifying and precisely measuring the degree of their achievement has arisen. The mentioned need led to the emergence of numerous and diverse diagnostic and benchmarking analytical tools, developed in the form of composite indices, which provide a summary of the state of performance of individual countries and / or regions in the field of achieving individual or a specific group of SDGs.

One of such synthetic indicators, proposed in order to assess the degree of achievement of SDGs related to the environmental performance of individual countries, is the Environmental Performance Index (EPI). In this sense, each individual EPI score represents a carefully designed multivariate quantitative measure of a country's environmental performance that encompasses national progress and efforts invested in protecting the environment (Neagu et al., 2017). Accepting the fact that without preserving the natural environment no development can be sustainable (Chowdhury & Islam, 2017), i.e. that environment and natural resources are the foundation of sustainable development (Samimi et al., 2011; Nguyen et al., 2025), it is not surprising why examining the complex relationship between economic development and environmental performance is of great importance for creators of national (sustainable) development policies and strategies.

The complexity of the aforementioned relationship essentially arises from its nature, which can briefly be described as a "*two-way street*". Actually, intensive fostering of a country's economic growth and development, as a prerequisite for a better quality of life and population's standard of living, necessarily implies, in general, a negative impact on ecosystems, and quality of environmental elements (i.e. land, water, air), thus suggesting that a higher level of a country's economic development is associated with lower environmental performance, and vice versa. At the same time, a higher level of economic development and income allows countries and business entities to invest more in cleaner technologies and renewable energy sources, thereby achieving positive effects in terms of mitigating environmental degradation and climate change consequences. Additional arguments in support of the described complexity can be extracted if developed and developing countries are analyzed separately. These are just some of the reasons why published studies have yielded mixed results and differing conclusions about the nature of the observed relationship.

Therefore, this paper examines the contribution of selected European countries to the achievement of sustainable development goals, from the perspective of recorded environmental performance, as well as the nature of its relationship with their level of economic development in 2023. The objectives of this research are fourfold:

(1) a detailed demonstration of statistically valid combined application of cluster analysis (CA) and one-way ANOVA method in the domain of the defined research subject,

(2) creation of ANOVA-verified classification of selected European countries into certain number of internally homogeneous / externally heterogeneous clusters based on the corresponding values of three key EPI components (i.e. Environmental health, Ecosystem vitality and Climate change) in 2023,

(3) an investigation of the relationship between environmental performance (i.e. categories of the proposed, EPI-based and ANOVA-verified, CA classification) and GDP per capita (as a measure of the achieved level of economic development) for the observed European countries in 2023, and

(4) an interpretation of the characteristics of the formed clusters of countries from the perspective of the used indicators of economic and environmental performances.

In addition, the research hypotheses addressed and tested in this paper are as follows:

> H1: *There are pronounced disparities among the observed 38 European countries in terms of their environmental performance, achieved in 2023.*
>
> H2: *European countries with higher values of GDP per capita, on average, are characterized by more favorable levels (categories) of environmental performance, recorded in 2023.*

The main novelty of the research presented in this paper lies in the applied (complex) methodological framework, based on the integration of univariate (one-factor ANOVA) and multivariate (cluster analysis) statistical methods, but also in the demonstration of the dual analytical role for which the ANOVA method can be used in the analysis (described in detail in Section 3). In addition, the proposed CA classification of the observed European countries according to selected indicators of environmental performance, together with the results of examining the nature of the relationship between their environmental achievements and economic development, can enhance academic understanding of the analyzed phenomenon, and also provide valuable insights for sustainability policy makers.

Accordingly, the paper is structured as follows. After the Introduction, Section 2 contains the key determinations of EPI, of which sub-indicators were used in the classification of the observed countries, as well as a brief overview of selected empirical studies related to the subject and objectives of this research. Section 3 includes detailed explanation of the methodological framework used, while a description of variables, sources and spatial–temporal coverage of data, as well as the obtained clustering results and ANOVA-based quality evaluation of the proposed classification, are presented in Section 4. Section 5 provides the results of the ANOVA-based investigation of the relationship between environmental performance and GDP per capita for the observed European countries in 2023, as well as a discussion of obtained results. Finally, concluding remarks are given in Section 6.

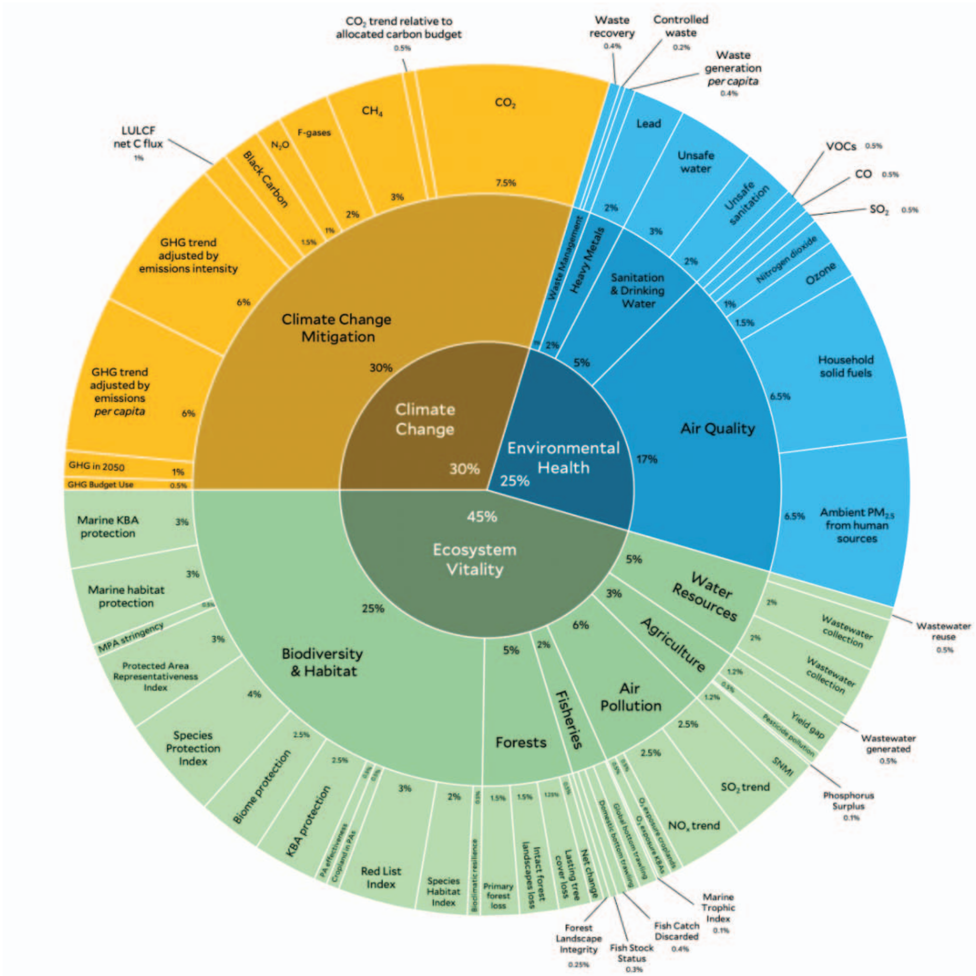
2. Literature review

In this section, a brief overview of selected empirical studies relevant to the observed research area is presented, with special focus on the explanation of main methodological issues regarding the Environmental Performance Index, since its composite scores and sub-indicators' values have a crucial role in the conducted research.

2.1. Environmental Performance Index – key methodological determinations

The Environmental Performance Index (EPI) was created as a result of the joint work of environmental experts and statisticians at the Yale University Center for Environmental Law & Policy and the Columbia University Center for International Earth Science Information Network, with the generous support of the McCall MacBain Foundation. According to its creators, the analytical effort undertaken to develop EPI composite index represents, without exaggeration, the most comprehensive global environmental analysis ever conducted (Wolf et al., 2022, p. XI). The scale and complexity of the aforementioned effort can best be seen through the EPI structure (Figure 1).

Figure 1: Detailed structure of the EPI composite indicator



Source: EPI 2024 Report (Block et al., 2024, p. X)

The EPI index synthesizes information obtained from 58 different indicators of environmental performance, distributed across 11 separate environmental issues. Their aggregated values, after weighting and subsequent aggregation, are used to form the values of the following three key EPI components, which also represent three important goals of sustainable development: *Improving environmental health*, *Protecting ecosystem vitality* and *Mitigating climate change*. The final EPI score, obtained as a result of weighting and aggregating the synthesized values of these three components, represents a composite value (ranging from 0 to 100) that is used to rank 180 countries in terms of their individual performance and progress in the field of achieving sustainable development and meeting the set sustainability goals, but also providing a summary of the situation at regional and global level in the domain of the aforementioned issue. The EPI and its components provide a list of comparable numerical values that allows for the separation of leading countries and those lagging behind in terms of achieved environmental performance and, based on the possibility of comparison, provide practical guidelines for countries striving for a sustainable future and meeting the SDGs (Block et al., 2024).

2.2. Research background

Examining the relationship between differently structured socio-economic and environmental dimensions of development in selected groups of countries represents a highly attractive research niche among members of the scientific community. The great interest of researchers in the mentioned analytical area, measured by the number of published empirical studies, is not surprising, given the importance of achieving and monitoring the level of realization of SDGs at the level of national economies in the modern global economic environment. In this context, different variables were used as adequate representatives of socio-economic (e.g. level of education, population density, Human Development Index [HDI], Quality of Life Index, GDP per capita or growth rate, etc.) and environmental dimension (e.g. CO_2 emission, Environmental Sustainability Index, Human Sustainable Development Index, Sustainable Development Goals Index, Environmental Performance Index [EPI], etc.). In accordance with the research objectives in this paper, in Table 1, the key methodological determinants of selected empirical studies of a similar research character, based on the use of EPI and / or its components, as proxy variables of the environmental development dimension, are presented.

Table 1: List of selected empirical studies on dependency / interdependency between EPI and economic performance indicator(s)

No.	Author(s) / (year)	Temporal coverage	Spatial coverage	Methodology approach
1.	Samimi et al. (2010)	2008	20 developing countries	WLS multiple regression analysis
2.	Samimi et al. (2011)	2006–2010	114 countries worldwide	GLS panel data regression analysis
3.	Duasa & Afroz (2013)	2010	all countries listed by the UN	OLS & GMM multiple regression analysis
4.	Bucher (2016)	2014	43 European countries	Hierarchical clustering & regression analysis
5.	Neagu et al. (2017)	2016	166 countries worldwide	Quadratic simple regression analysis
6.	Chowdhury & Islam (2017)	2008–2016	5 BRICS countries	Simple correlation analysis
7.	Fakher & Abedi (2017)	1983–2013	selected developing countries	ARDL model, co-integration & causality tests
8.	Sinevičienė et al. (2018)	2000–2010	15 developing countries (Europe)	GLS panel data multiple regression analysis
9.	Gallego-Álvarez et al. (2018)	2008	24 countries in Latin America	PCA & multiple regression analysis
10.	Lukáč et al. (2020)	2008–2018	38 selected OECD countries	PCA & hierarchical cluster analysis
11.	Boleti et al. (2021)	2002–2012	88 selected OECD countries	OLS panel data multiple regression analysis
12.	Repiská et al. (2022)	2018	15 selected EU countries	Hierarchical cluster analysis
13.	Dima et al. (2024)	2023	167 countries worldwide	Geographically weighted multiple regression
14.	Ristić & Gavrić (2024)	2022 (2023)	27 EU countries	Correlation & hierarchical cluster analysis
15.	Saraiva & Caiado (2025)	mainly 2020	206 countries worldwide	Non-hierarchical cluster analysis & PCA
16.	Karountzos et al. (2025)	2023	123 countries worldwide	Correlation and multiple regression analysis

Source: Authors' representations

A detailed analysis of the content of research studies in Table 1 additionally confirms the expressed variability in terms of analytical scope (spatial and temporal), implemented methodological approach, as well as the selection of indicators used to measure the level of socio-economic development, regardless of the unification of environmental variables. In the methodological context, compared to the recorded rare cases of implementation of correlation and cluster analysis, the application of different types of multiple regression (econometric) analysis can be singled out as dominant, with differences regarding the role (dependent or independent) assigned to environmental variables. The described variability, consequently, did not bypass the results and conclusions of studies based on the applied regression analysis. More precisely, the statistically significant impact of GDP per capita or another indicator of economic development (e.g. HDI or GDP growth rate) on environmental performance (measured by the EPI scores or values of its key components), as dependent variable, was confirmed in studies, listed in Table 1, with the following ordinal numbers: 2, 3, 5, 8, 9, 11. And while in most cases the statistical significance of the positive impact of used economic indicators on the environmental (EPI, dependent) variable has been proven, Gallego- Álvarez et al. (2018) confirm the presence of a negative and statistically significant impact of GDP per capita, in the case of 24 selected Latin American countries.

Similar results, but in the case of 86 developing countries and using HDI as an independent variable in the model, were also presented by Samimi et al. (2011), contrary to the research conducted by Bucher (2016), whose results suggest the absence of a statistically significant impact of HDI on EPI variable. In contrast, the studies conducted by Karountzos et al. (2025), Dima et al. (2024), Fakher and Abedi (2017), and Samimi et al. (2010) provide empirical evidence supporting the existence of a positive and statistically significant impact of environmental quality, measured by the EPI (serving as the explanatory variable), on economic performance, measured by GDP per capita or real GDP growth rate.

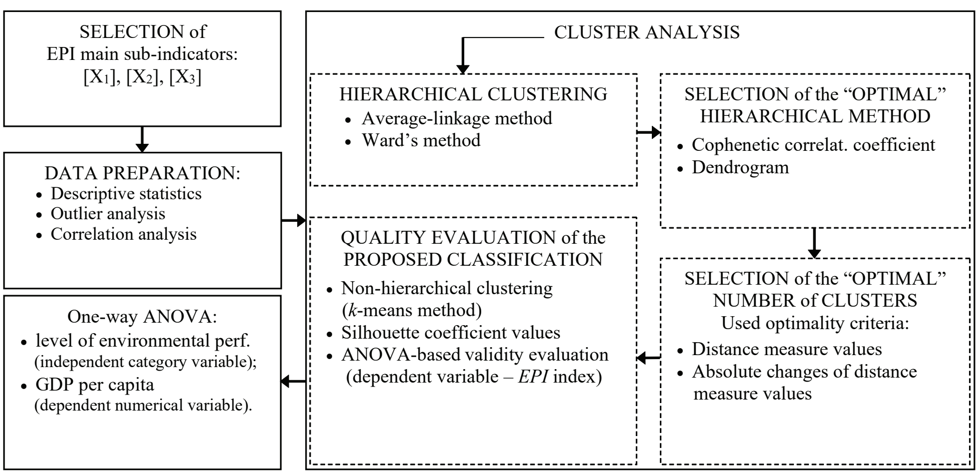
Although the existing literature provides valuable insights into the relationship between environmental performance and economic development, several limitations remain evident. Most previous studies rely predominantly on regression-based approaches and focus on examining direct causal relationships between used indicators. Consequently, less attention has been devoted to identifying homogeneous groups of countries according to environmental performance and to analyzing economic disparities between such groups using integrated multivariate statistical procedures. These limitations indicate the existence of a research gap that justifies the application of alternative methodological approaches.

In this context, the originality of the conducted research lies primarily in the statistically valid implementation of a specific methodological framework, based on the combined application of hierarchical cluster analysis and the ANOVA method for the purpose of examining the relationship between GDP per capita and achieved environmental performance. According to the authors' knowledge, the applied combination of temporal-spatial data coverage, statistical approach and variables, as relevant indicators of economic and environmental dimensions of development, has not been exploited in the existing literature so far in the analysis of this research problem. Beyond its methodological contribution, the study also provides a theoretical contribution to the existing literature by enriching the understanding of the nature of the relationship between economic and environmental performance, particularly in the context of European economies. It is expected that the presented results will contribute to the advancement of theoretical knowledge within this research niche by offering additional empirical evidence and supporting a more refined interpretation of the economic–environmental nexus. Moreover, regardless of the similarity of research objectives, the results obtained in studies listed in Table 1, generally, cannot be considered directly comparable to the results presented here, due to the existence of analytical-methodological differences outlined above.

3. Methodology

A schematic representation of the methodological framework used, supplemented by detailed explanations of the applied statistical methods and their key determinants, is given in Figure 2.

Figure 2: Schematic representation of the used research methodology framework



Source: Authors' representation

Cluster analysis is a generic term used to describe a wide range of multivariate statistical procedures specifically designed to reveal "*natural*" structure, i.e.

classification of observation units, within complex and heterogeneous data sets (Gore, 2000; Stamenković et al., 2021). Drawing on the essential definitions of the proximity concept, the common primary goal of these procedures is to divide a given set of multivariate observations into an a priori unknown but typically small number of mutually exclusive and, to the greatest extent possible, internally-homogeneous and externally-heterogeneous, meaningful groups, known as clusters (Stamenković & Milanović, 2022). Actually, the outcome of any clustering procedure is a classification structure made up of a certain number of clusters, where observations within the same group are considered to have "*high*" mutual similarity (i.e. proximity), but also "*low*" similarity with observations within other clusters, in terms of the values of simultaneously analyzed variables (Bijnen, 1973).

In this context, after thorough data preparation of the selected key EPI components, CA was used to extract a classification of the analyzed countries according to their recorded level of environmental performance. Within this phase, CA plays the role of the central method, while ANOVA is used as an auxiliary method for evaluating the quality of the proposed clustering solution. From a methodological perspective, the application of CA is characterized by several specific features. The optimal hierarchical clustering method and the appropriate number of clusters within the obtained tree-classification structure were selected using objective statistical criteria, thereby reducing subjectivity in the clustering procedure. In addition, the results of hierarchical (HCA) and non-hierarchical (Non-HCA) clustering methods were comparatively evaluated using silhouette coefficient values in order to identify the most reliable classification of countries. In applying ANOVA, the role of the dependent variable was assigned to the final EPI scores, while the clusters in the proposed classification structure were used as individual categories of the independent variable. In the next research phase, the one-way ANOVA method was re-applied, this time as the central analytical method, in order to examine the statistical nature of the relationship between the level of economic development, measured by GDP per capita, and environmental performance, represented by separate groups in the proposed CA classification (as categories of independent variable), using selected European countries as the research sample. The purpose of this research step is to test the hypothesis regarding the presence of statistically significant differences in average GDP per capita values among clusters of European countries representing different levels of environmental performance. The practical demonstration of the dual analytical role of ANOVA within the same research framework represents one of the key methodological contributions of the conducted research.

The analysis of the collected data and all necessary statistical calculations were performed using IBM-SPSS Statistics version 21 and Microsoft Office Excel. The interpretation of the obtained results is complemented by appropriate tabular, cartographic, and statistical graphical representations.

4. Empirical data and analysis

In this section, we present the research aspects related to the selected environmental performance variables, the sources used, and the spatial–temporal scope of empirical data, together with the preliminary data analysis and the results of CA-based and ANOVA-verified classification of analyzed countries according to their environmental performance.

4.1. Variables, sources of data, and temporal-spatial scope of the research

For the realization of defined objectives, and in accordance with the methodological framework, secondary data of different sets of numerical variables from different sources were collected. For the CA-based classification of observation units in terms of various aspects of achieved environmental performance, data on the three key EPI components (i.e. Environmental health, Ecosystem vitality, Climate change) were used, while the ANOVA-based evaluation of its quality was carried out using the *composite EPI scores* as the dependent variable. The source of data for these environmental variables is the *2024 Environmental Performance Index Report* (Block et al., 2024, p. 11). Additionally, the ANOVA-based evaluation of the relationship between economic and environmental performances was conducted using GDP per capita (expressed in constant 2021 international dollars, converted by purchasing power parities – PPPs) (International Monetary Fund [IMF], 2024), as dependent variable – an indicator of economic development, and created groups of countries, as individual categories of (independent) environmental variable. The last available data for all analyzed variables refer to 2023. The observation units include the following 38 European countries: 27 EU member states, 6 candidate countries and potential candidates for EU membership (Serbia, Montenegro, North Macedonia, Moldova, Albania, Bosnia & Herzegovina) and 5 countries that are not part of the EU by their own decision (Iceland, Norway, Great Britain, Belarus, Switzerland).

4.2. Classification of European countries by the main EPI components

In order to classify the analyzed European countries into an appropriate number of internally-homogeneous and externally-heterogeneous clusters, in terms of their achieved environmental performance, a hierarchical agglomerative cluster analysis was conducted using the three key EPI components. The normalization procedure for the input variables was not applied, since their values result from the aggregation of previously normalized and weighted values of a large number of original indicators included in the multivariate EPI structure (Figure 1), and therefore range from 1 to 100 index points. The values of the arithmetic mean ($\overline{x}$), median (m_e) and coefficient of variation (v) for the used input variables are presented in Table 2.

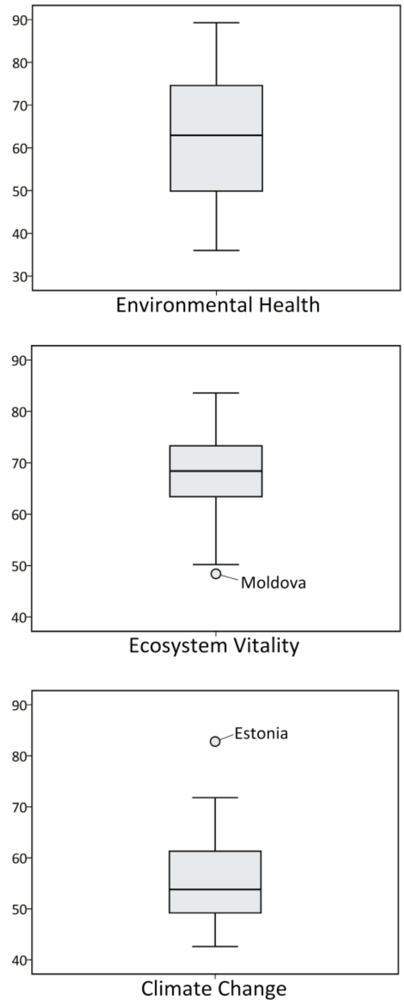
Table 2: Values of key descriptive statistical measures of EPI components

EPI sub-indicators		$\bar{x}$	m_e	v
Environmental health	(X_1)	62.77	62.95	23.4%
Ecosystem vitality	(X_2)	67.51	68.40	12.9%
Climate change	(X_3)	55.79	53.80	16.3%

Source: Authors' calculations

Within the preparation phase and preliminary data analysis, the detection of a possible presence of univariate and multivariate atypical observations (i.e. outliers) was carried out, using box-plots and Mahalanobis distance measure values, respectively. Constructed diagrams for individual variables (Figure 3), as well as the approximate values of their positional (m_e) and calculated ($\bar{x}$) measures of central tendency, unequivocally suggest the absence of true one-dimensional outliers. One *"suspected"* non-standard observation was detected for each of the variables X_2 [MDA] and X_3 [EST]. It is also important to emphasize that Estonia represents a multivariate outlier, since it is characterized by a Mahalanobis distance measure value (MD_{EST} = 11.665) which is significantly above the corresponding critical value of the chi-square distribution, i.e. $\chi^2_{(3;\ 0.975)}$ = 9.348. Elimination of this multivariate observation from further analysis was not carried out, since it represents an extremely small and very significant part of the available data set, especially in terms of territorial data coverage. Finally, since the values of the relative measure of dispersion (v) for all three variables are lower than 30%, it is clear that there is a relative homogeneity of the data in their distribution, with the lowest variability among the analyzed countries being recorded in the case of variable X_2 (i.e. v_2 = 12.9%).

Figure 3: Box-plots for individual EPI components

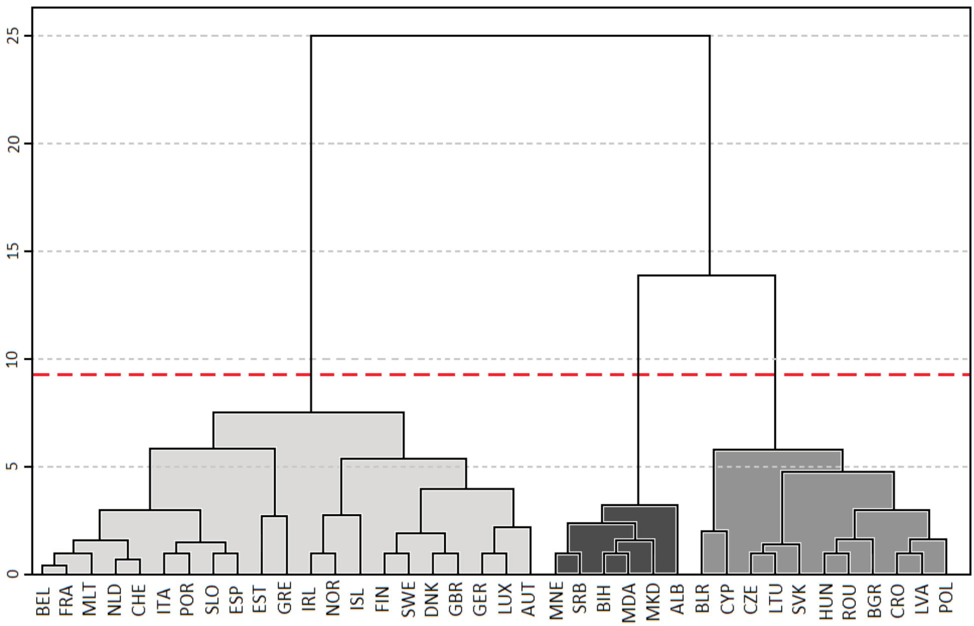


Source: Authors' calculations

In addition to the above, the results of a simple linear correlation analysis suggest the absence of a very strong interdependence of the variables, since the correlation coefficient values (r) range from $r_{x_2x_3} = 0.391$ to $r_{x_1x_3} = 0.506$. The results of the hypothesis testing procedure for the parameter ρ confirmed the statistical significance of the linear correlation in the case of all three pairs of analyzed variables.

On preprocessed multivariate data of three key EPI components, a hierarchical agglomerative classification procedure was implemented, based on the application of Average-linkage and Ward's method, using squared Euclidean distance as the appropriate distance measure. Given that it is characterized by a higher value of Cophenetic correlation coefficient (CpCc = 0.592), but also by a more visually acceptable classification structure of European countries, the Ward's method was chosen as optimal, against the (alternative) Average-linkage method (CpCc = 0.591). A graphical display of the hierarchical grouping results of analyzed 38 countries according to EPI components, in the form of a dendrogram, is presented in Figure 4.

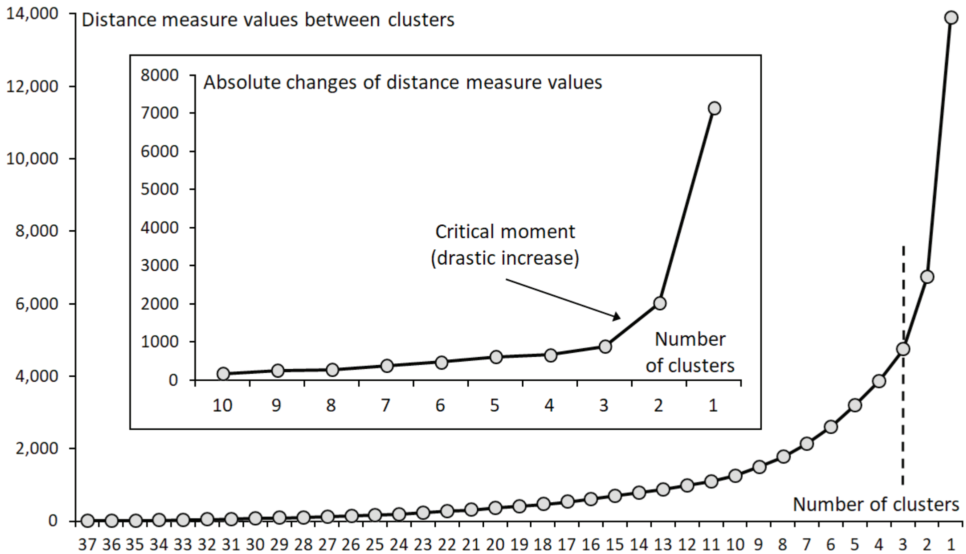
Figure 4: Graphical representation of the obtained hierarchical structure



Source: Authors' calculations

Three visually distinctive groups in the structure of the complete hierarchical tree on the dendrogram are marked with different shades of gray. Statistical verification of this subjective statement made by authors, i.e. the selection of the "*optimal*" number of clusters, was performed using the criteria presented in the methodological framework. Graphical representations of the movement of distance measure values between countries and/or groups of countries and their absolute increase in successive steps of the agglomeration process are presented in Figure 5.

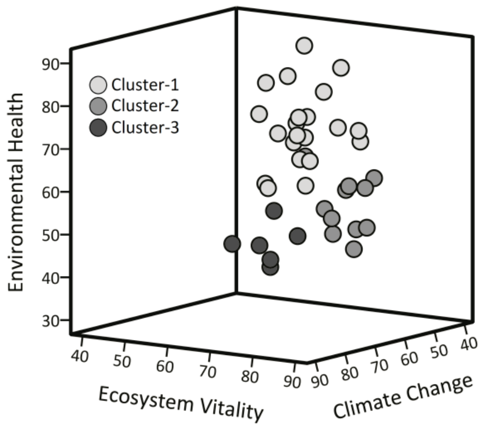
Figure 5: Graphical display of values and increments of distance measure between groups

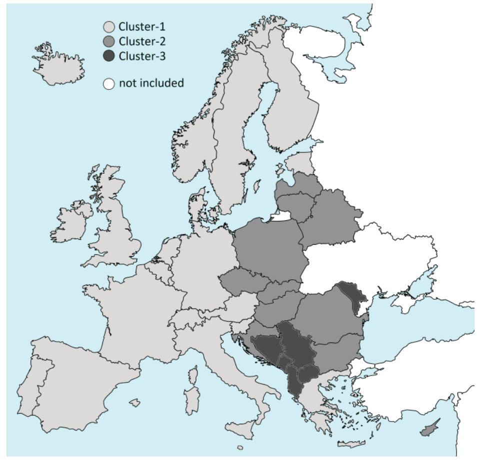


Source: Authors' calculations

In Figure 5, a sudden interruption of the continuous and gradual increase in the value of distance measure between the formed groups, as well as its absolute increase, which occurred in the 36th step of the agglomeration process at the moment of extracting a classification solution that includes two clusters. is clearly visible. Since the observed drastic increase in the optimality criteria suggests the merging of highly heterogeneous groups, the solution that precedes the described changes (i.e. the three-cluster solution) stands out as the optimal clustering solution. Additional (graphical) confirmation of the selected hierarchical solution is given in Figure 6 and the distribution of countries by extracted groups in Table 3.

Figure 6: Visual representations of environmental classification of selected European countries





Source: Authors' representations

Table 3: Distribution of European countries by extracted clusters

Cluster code	Environmental performance	No. of countries	Countries within individual clusters
c-1	"*high-level*"	21	GBR, IRL, ISL, BEL, NLD, LUX, CHE, GER, FRA, DNK, FIN, SWE, NOR, EST, ITA, GRE, MLT, ESP, POR, SLO, AUT
c-2	"*average-level*"	11	LTU, LVA, POL, BLR, SVK, CZE, HUN, ROU, BGR, CRO, CYP
c-3	"*low-level*"	6	ALB, MNE, BIH, MKD, SRB, MDA

Source: Authors' calculations

Additional quantitative verification of the proposed classification is obtained by comparing values of the silhouette coefficient, as a statistical measure intended for a comprehensive evaluation of the quality of the obtained clustering results, calculated for hierarchical and non-hierarchical classification structures. More precisely, the overall silhouette coefficient value ($\overline{\overline{silh}}$ = 0.629), calculated for the hierarchical classification, is clearly higher than the comparable value of the non-hierarchical alternative ($\overline{\overline{silh}}$ = 0.526), thus indicating that the created hierarchical solution is characterized by higher quality.

4.3. ANOVA-based validity evaluation of the proposed classification

Evaluation of validity and practical significance of the CA classification was conducted by implementing one-way ANOVA and testing the following statistical hypotheses:

> H0: *There is no statistically significant difference between the average EPI scores for the observed three groups of countries;*
>
> H1: *There is a statistically significant difference between the average EPI scores for at least two groups of countries.*

The identified level of environmental performance for individual clusters represents an independent (categorical) variable with 3 treatments [c-1 (high-level); c-2 (average-level); c-3 (low-level)], while EPI represents the dependent (continuous numerical) variable. Based on the dependence of final EPI scores on its 3 components' values, used in CA as input variables, the validity of the proposed classification will be confirmed if there is sufficient empirical evidence to reject H0 hypothesis. Since ANOVA is a parametric method, the normality of dependent variable's distribution across the selected groups of countries was tested using the Anderson-Darling test. The obtained results (Table 4) suggest that there is not enough evidence to reject the null hypothesis about the normality of the dependent variable's distribution in case of all three clusters of countries, since the resulting p-values are higher than defined significance level, $\alpha = 0.05$. The normality of EPI distribution by clusters is expected, given the absence of univariate (true) outliers within them (Figure 7-left). The fulfillment of the assumption regarding the homogeneity of population variances was also confirmed by the results of the Levene's test (i.e. test statistic = 0.848, with resulting p-value (0.437) > $\alpha = 0.05$).

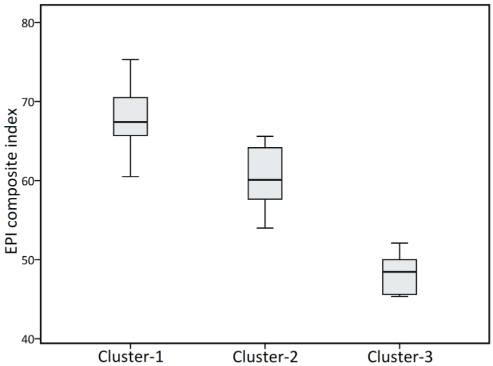
Table 4: Results of EPI distribution normality testing

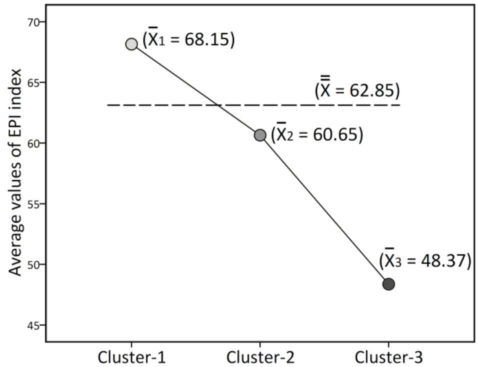
Dependent variable (Y_i)	Categories of independent variable	Anderson-Darling test	
		statistics	p-values
EPI	cluster-1	0.330	0.488
	cluster-2	0.294	0.533
	cluster-3	0.248	0.599

Source: Authors' calculations

After a detailed check and confirmation that all key assumptions were met, a one-way ANOVA was conducted to make a decision regarding the defined statistical hypotheses, Since the realized test significance level (p-value = 0.000), for the calculated value of the F test statistic ($F_{(\alpha = 0.05;\ v1 = 2;\ v2 = 35)} = 59.644$), is lower than the defined significance level ($\alpha = 0.05$), it can be concluded that there is enough empirical evidence to reject H0 and accept the alternative H1 hypothesis, claiming that there is a statistically significant difference between the average EPI scores of at least two of three groups of countries, separated according to the level of environmental performance.

Figure 7: Box-plots (left) and means plot (right) of EPI variable for individual clusters





Source: Authors' calculations

To identify specific clusters of countries between which there is a statistically significant difference in the arithmetic means of the dependent EPI variable, a multiple comparison of all possible pairs of independent variable categories was conducted using the Fisher's Least Significant Difference (LSD) post-hoc test (Table 5).

Table 5: Results of the Fisher's LSD post-hoc test

Categories of independent variable	Clusters for comparison	Means differences	p-values
cluster-1 ("*high-level*")	cluster-2	7.502	0.000
	cluster-3	19.781	0.000
cluster-2 ("*average-level*")	cluster-1	–7.502	0.000
	cluster-3	12.279	0.000
cluster-3 ("*low-level*")	cluster-1	–19.781	0.000
	cluster-2	–12.279	0.000

Source: Authors' calculations

The results of post-hoc analysis suggest, with the Bonferroni corrected test significance level ($\alpha^* = 0.0083$), that there is a statistically significant difference between all three categories (clusters) of European countries in terms of the corresponding average EPI scores (Figure 7-right), thus confirming the validity and practical significance of proposed CA classification.

5. Results and discussion

This section focuses on an ANOVA-based investigation of the interdependency between economic and EPI performances, using the previously formed CA classification of European countries and GDP per capita as relevant input variables, and discusses the obtained results.

5.1. ANOVA-based evaluation of the relationship between economic and EPI performances

To examine the nature of the relationship between economic development and environmental performance levels of 38 European countries in 2023, a one-way ANOVA was applied to test the following statistical hypotheses:

> H0: *There is no statistically significant difference between the average GDP per capita values for the observed three EPI-based clusters of countries;*
>
> H1: *There is a statistically significant difference between the average GDP per capita values for at least two EPI-based clusters of countries.*

The identified environmental performance level of individual groups represents an independent (categorical) variable with 3 categories [c-1 (high-level); c-2 (average-level); c-3 (low-level)], while GDP per capita is the dependent (continuous numerical) variable. The assessment of assumption validity for ANOVA revealed the presence of one true outlier [LUX], in terms of GDP per capita, within the group of countries characterized by high environmental performance (Figure 8-left). The presence of the outlier affected the results of testing the hypotheses about the normality of GDP per capita distribution for individual clusters (Table 6, columns III-V). For eliminating negative effects, [LUX] was removed from further analysis. The results of the repeated normality testing procedure are given in Table 6 (columns VI-VIII).

Table 6: Results of GDP per capita distribution normality testing

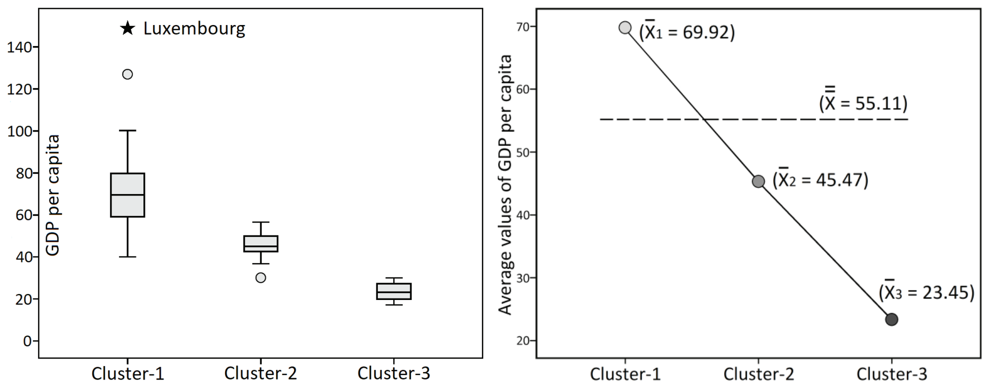
Dependent variable (Y_i)	Categories of independent variable	38 European countries			without Luxembourg (outlier)		
		Anderson-Darling test		Decisions	Anderson-Darling test		Decisions
		statistics	p-values		statistics	p-values	
GDP per capita	Cluster-1	0.987	0.011	H_1	0.496	0.189	H_0
	Cluster-2	0.224	0.764	H_0	0.224	0.764	H_0
	Cluster-3	0.264	0.546	H_0	0.264	0.546	H_0

Source: Authors' calculations

The obtained results suggest that there is not enough evidence to reject the null hypothesis about the normality of GDP per capita distribution in case of all three clusters of countries, since the resulting p-values are higher than the defined significance level, $\alpha = 0.05$.

The ANOVA results suggest that there is sufficient empirical evidence to accept the alternative hypothesis, claiming that there is a statistically significant difference between the average GDP per capita values of at least two groups of countries, separated according to their environmental performance level, since the p-value (0.000), obtained for F test statistic ($F_{(\alpha = 0.05;\ v1 = 2;\ v2 = 34)} = 22.982$), is less than the defined level of test significance ($\alpha = 0.05$).

Figure 8: Box-plots (left) and means plot (right) of GDP per capita for individual clusters



Source: Authors' calculations

To identify specific clusters of countries between which there is a statistically significant difference in the arithmetic means of the dependent GDP per capita variable, a multiple comparison of all possible pairs of independent variable's categories was conducted using the Games-Howell post-hoc test (Table 7), since the assumption of population variances homogeneity was not confirmed by the Levene's test results (statistic = 3.324, p-value (0.048) < $\alpha = 0.05$).

Table 7: Results of Games-Howell post-hoc test

Categories of independent variable	Clusters for comparison	Means differences	p-values
cluster-1 (“*high-level*”)	cluster-2	24.444	0.000
	cluster-3	46.469	0.000
cluster-2 (“*average-level*”)	cluster-1	–24.444	0.000
	cluster-3	22.025	0.000
cluster-3 (“*low-level*”)	cluster-1	–46.469	0.000
	cluster-2	–22.025	0.000

Source: Authors’ calculations

The obtained post-hoc analysis results suggest, with the Bonferroni corrected test significance level ($\alpha^* = 0.0083$), that there is a statistically significant difference between all three pairs of categories (clusters) of European countries in terms of the corresponding average GDP per capita values. Figure 8 (right) visually confirms the interpreted ANOVA results.

5.2. Interpretation of the relationship between economic and EPI performances

Starting from the presented outcomes of the twofold ANOVA application, based on the proposed CA classification, as well as a comparative overview of the mean values of EPI and GDP per capita by the formed clusters of European countries (Table 8), the interpretation and discussion of the overall examination results of the relationship between economic development and environmental performance, for the observed countries in 2023, were carried out in the context of formulated research hypotheses. In this sense, the following observations can be made:

- Within the cluster of countries characterized by a high level of environmental performance, the presence of EU countries that gained membership before 2000 is dominant, along with non-EU Western European countries. This classification outcome is fully expected and confirms the analytical power of CA and the practical importance of the proposed typology, since the listed 21 countries are positioned in the first 29 places in the EPI world ranking in 2023 (Block et al., 2024). Cluster named “*average level of environmental performance*” includes all remaining EU countries, which gained membership in enlargement waves after 2000, and [BLR] as a non-EU country. Finally, all 6 candidate countries and potential candidates for EU membership are allocated within cluster-3. Generally, these are the worst positioned European countries in terms of recorded environmental performance in 2023, both according to the classification results and EPI world ranking, where they occupy positions above 50th place.

Table 8: Comparative overview of EPI and GDP per capita mean values by clusters in 2023

Clusters' size	Environmental performance	Averages	
		EPI	GDP pc
$n_1 = 21$	high-level	68.1	73.67
$n_2 = 11$	average-level	60.6	45.47
$n_3 = 6$	low-level	48.4	23.45
Total mean values	$m_o = m_e$ = high-level	$\bar{x} = 62.9$	$\bar{x} = 57.58$

Note: m_o (mode), m_e (median), $\bar{x}$ (arithmetic mean).

Source: Authors' calculations

● The regularity observed in the distribution of average EPI scores by clusters of analyzed countries (Table 8, column 3) fully justifies assigned descriptive names to them, regarding their level of environmental performance in 2023 (Table 8, column 2). The highest average EPI score is held by countries in cluster-1, while the lowest average is reserved for members of cluster-3. The difference in their EPI averages of approximately 40% clearly indicates the extent of disparities present between the countries in these groups in terms of environmental performance in 2023. The average EPI score of cluster-2 is 12.5% below the corresponding value of cluster-1, that is, 25% above the EPI average of cluster-3 and close but slightly below the EPI average of all 38 countries. Compared to the EPI average in the entire sample (62.9), the average of cluster-1 is 8.5% (or nearly 5 points) above, while the corresponding value of cluster-3 is 23% (≈15 index points) below the comparable sample value. The described practical and, according to the ANOVA results, proven statistical significance of differences between the EPI averages of the three clusters in the structure of the highly interpretable CA classification, indicate the presence of pronounced disparities in terms of recorded environmental performances of the observed European countries in 2023. Consequently, it can be concluded that the validity of the first research hypothesis has been confirmed.

● The ranking of clusters according to average GDP per capita (Table 8, column 4) is completely identical to their ranking in terms of environmental performance. It is evident that the countries distributed within cluster-1 (i.e. high environmental performance) also recorded the highest GDP per capita average (i.e. high level of economic development), and vice versa in the case of cluster-3 (the lowest environmental performance and GDP per capita average), while cluster-2 is characterized by averages of EPI and GDP per capita, generally, between the previous two groups. The statistical significance of differences in average GDP per capita values between all three clusters of European countries, formed according to environmental performance, is clearly proven by the results of the ANOVA-based post-hoc analysis, and thus the validity of the second research hypothesis, claiming that European countries with higher GDP per capita values, on average, are characterized by more favorable levels of environmental performance, recorded in 2023, is indisputably confirmed.

Although direct comparability of obtained research results with published empirical studies is not fully feasible or valid due to methodological differences and "*limitations*", apostrophized in Section 2, the identification of a "*positive*" statistically significant relationship between economic development (measured by GDP per capita) and environmental performance levels in this paper, in general, confirms the findings and conclusions made by Duasa and Afroz (2013), Neagu et al. (2017), Sinevičienė et al. (2018), Boleti et al. (2021). The common denominator of the research approaches by mentioned authors is the application of multiple regression analysis and the use of EPI (or its main components) as a dependent variable. In addition, Karountzos et al. (2025), Dima et al. (2024), Fakher and Abedi (2017) and Samimi et al. (2010) also confirm the existence of a positive statistically significant relationship between the observed development dimensions, but, contrary to previous studies, they used EPI as an independent variable in the regression models, examining its impact on GDP per capita or GDP growth rate, as dependent variables. Ristić and Gavrić (2024) came to similar findings, investigating the correlation between EPI variations and the Legatum Prosperity Index (as an indicator of quality of life and economic wealth) for 27 EU countries, using hierarchical cluster and correlation analysis. On the other hand, Samimi et al. (2011) and Repiská et al. (2022) also presented empirical evidence in support of the existence of a positive statistically significant relationship between the economic and environmental performance of the analyzed countries, but using HDI as an indicator of economic development instead of GDP per capita.

These findings suggest that environmental performance is closely associated with the level of economic development, indicating that higher-income countries are generally more capable of investing in environmental protection, technological innovation, and institutional capacity for implementing environmental policies. At the same time, the observed clustering pattern implies that economic development and environmental quality are not isolated dimensions but tend to co-evolve within similar structural and institutional frameworks. This reinforces the importance of integrated policy approaches that simultaneously address economic growth and environmental sustainability, particularly in the case of less developed countries aiming to converge towards higher environmental performance standards.

6. Conclusions

In this paper, according to the defined subject and the research objectives, a two-stage statistical framework was conducted (based on the combined application of hierarchical agglomerative clustering procedure and one-way ANOVA in a dual analytical role), which primarily focused on the investigation of the relationship between environmental performance (determined as categories of the proposed EPI-based CA classification) and achieved economic development (measured by GDP per capita) on the example of 38 European countries in 2023. In this context, the results of the hierarchical (ANOVA-verified) classification, obtained using the representative values of three key EPI components, in the first research phase, unequivocally confirm the presence of pronounced disparities among the observed European countries in terms of recorded environmental performance in 2023, since the solution that includes three clusters was singled out as optimal. The formed clusters of European countries, with assigned descriptive names that reflect their rank in terms of environmental performance level (i.e. high, average, low), were used as a categorical independent variable in the second research phase, aimed at testing the validity of the second research hypothesis that claims: European countries with higher GDP per capita, on average, are characterized by more favorable categories of environmental performance, recorded in 2023. The ANOVA-based results, within the second research stage, unequivocally confirm the presence of a positive statistically significant relationship between the achieved economic development level and EPI-based environmental performance.

The interpretation of the clusters' profiles, based on the comparison of corresponding EPI and GDP per capita averages, also reveals another categorical component (named by the authors as *EU membership*), which can be seen as a possible cause of the present eco-disparities. It also supports the statistical significance of the identified positive relationship, considering its indirect relation with the level of economic development of the analyzed European countries. Actually, based on the average EPI and GDP per capita values, the formed clusters can be ranked as follows: cluster-1 (dominant presence of "*older*" EU members) > cluster-2 (dominant presence of "*newer*" EU members) > cluster-3 (candidates and potential candidates for EU membership). The possible cause of the aforementioned ranking may be the countries' EU membership and the length of that membership. Actually, due to the numerous economic and market benefits it brings, EU membership gives countries greater opportunities for faster economic development.

Logically, the economic development of EU countries is directly related to the length of their membership. In addition, quite a long tradition in terms of adopting and implementing legislation aimed at establishing a green economy and achieving SDGs is an inherent characteristic of the EU, in relation to countries beyond its borders. Consequently, the "*older*" EU countries have a significant head start and greater experience in achieving SDGs, but also a better economic basis for investing in cleaner technologies and renewable energy sources, or relocating eco-risky ("*dirty*") industries outside their borders, thereby achieving positive effects in mitigating environmental degradation and climate change consequences, compared to countries that joined the EU later on or not at all. In general, from the perspective of European countries, EU membership represents a necessary step in ensuring better conditions for achieving sustainable development. This interpretation contributes to the theoretical understanding of the economic–environmental nexus by highlighting the importance of supranational institutional frameworks, such as the EU, as a structural factor influencing the co-evolution of economic development and environmental performance. In this sense, EU membership is not only a formal status, but also a channel through which institutional quality, regulatory experience, and sustainability-oriented policies are progressively internalized, thereby strengthening the link between the observed development dimensions.

Furthermore, the obtained research results can provide valuable insights for sustainability policymakers, while the proposed methodological framework can serve as a suitable basis for assessing the current situation and monitoring future changes (progress or deterioration) in the positions of the observed countries with regard to their environmental performance, thereby supporting efforts aimed at mitigating existing disparities. In this context, the proposed methodological framework represents the main practical contribution of the study, as it can also be applied to a broader set of countries.

The present study is subject to several limitations that should be acknowledged. First, the analysis is based on cross-sectional data for a single year (2023), which does not allow for the capturing of dynamic changes or long-term temporal relationships between economic development and environmental performance. Second, although the EPI represents a comprehensive and widely used measure of environmental quality, it remains a composite indicator and is therefore subject to limitations inherent in the aggregation procedures and weighting schemes of its constituent components. Finally, the relatively limited degree of direct comparability of the obtained results with findings from previously published studies should also be noted, due to differences in methodological approaches, data sources, and sample selection.

Future research could extend the proposed methodological framework in several directions. A natural extension would involve incorporating a longitudinal dimension through a panel data analysis in order to capture the dynamic evolution of the relationship between economic development and environmental performance over time. In addition, future studies could include alternative measures of environmental quality and economic development, such as the ecological footprint, CO_2 emissions, or HDI, in order to test the robustness of the obtained results. Furthermore, the analysis could be expanded beyond the European context to include a broader set of countries at different stages of development, thereby enabling a more comprehensive global comparison. Finally, future research could incorporate regression techniques applied to individual country clusters formed on the basis of EPI sub-indicators, with the aim of examining the strength of the impact of EPI as an explanatory variable on GDP per capita as the dependent variable.

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Odnos između ekološke učinkovitosti i gospodarskog razvoja: dokazi iz europskih zemalja

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Sažetak

Polazeći od činjenice da bez snažnih napora usmjerenih na očuvanje prirodnog okoliša i ublažavanje posljedica klimatskih promjena nijedan razvoj ne može biti dugoročno održiv, osnovni cilj ovog rada je istražiti odnos između ekološke učinkovitosti i postignutog gospodarskog razvoja odabranih europskih zemalja. Za ostvarenje definiranih ciljeva korištena je inovativna (dvostupanjska) istraživačka metodologija, temeljena na kombiniranoj primjeni klaster analize i jednofaktorske ANOVA-e. Klasifikacija 38 europskih zemalja u različite skupine, temeljena na vrijednostima triju ključnih komponenti Indeksa ekološke učinkovitosti (EPI) za 2023. godinu, provedena je hijerarhijskom aglomerativnom klaster analizom. Dobiveno „optimalno" rješenje, koje se sastoji od triju klastera, nadopunjeno je rezultatima ANOVA-e radi procjene njegove statističke valjanosti te nedvojbeno potvrđuje postojanje izraženih razlika među promatranim zemljama u pogledu zabilježene ekološke učinkovitosti. Formirane skupine s dodijeljenim kategorijama (visoka, prosječna i niska ekološka učinkovitost) korištene su kao nezavisna varijabla u drugoj fazi analize, usmjerenoj na ispitivanje statističke značajnosti razlika između prosječnih vrijednosti BDP-a po stanovniku utvrđenih za tri klastera zemalja temeljenih na EPI-ju. Rezultati ANOVA-e nedvojbeno potvrđuju postojanje pozitivne i statistički značajne veze između postignutog gospodarskog razvoja i ekološke učinkovitosti temeljene na EPI-ju, za promatrane europske zemlje u 2023. godini. Dobiveni rezultati istraživanja mogu pružiti vrijedne uvide donositeljima politika održivosti te doprinijeti boljem razumijevanju prirode odnosa između gospodarskih i ekoloških pokazatelja.

Ključne riječi: *klaster analiza, jednofaktorska ANOVA, indeks ekološke učinkovitosti, BDP po stanovniku, europske zemlje*

JEL klasifikacija: *C12, C38, E01, O52, Q56*

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Deposit Insurance System under Different Financial Conditions*

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Abstract

The deposit insurance system is a fundamental component of financial stability, as it protects depositors and mitigates the risk of bank runs. However, its impact on bank risk is not unambiguous and depends on the phase of the economic cycle. The aim of this paper is to examine the differential effects of deposit insurance systems on bank stability before, during and after a financial crisis. The analysis employs a dynamic panel model estimated with the Arellano-Bond GMM estimator on a sample of the European Union (EU) and selected Southeast European (SEE) countries in the period from 2005 to 2014. Bank stability was proxied by the z-score and the share of non-performing loans. The results show that the deposit insurance system has a stabilising effect during a crisis, as it mitigates the risk of banking system instability, while risk appetite increase in the periods before and after the crisis, suggesting the presence of moral hazard. In line with the research results and the lessons learned during the Global Financial Crisis, the EU continues to discuss the completion of the third pillar of the Banking Union, namely the common European Deposit Insurance Scheme (EDIS). Although a consensus has not yet been reached among the Member States, due to differences in the characteristics of national financial systems, EDIS is seen as an instrument that could contribute to greater coordination and resilience of the banking sector in future crises.

Keywords: *bank stability, dynamic panel analysis, moral hazard, Banking Union*

JEL classification: *C33, E32, G21*

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1. Introduction

The deposit insurance system (DIS) is one of the fundamental instruments for protecting depositors and preserving the stability of the banking system. Its importance stems from the fact that the stability of banks is largely conditioned by the trust of depositors in the financial system, and that the loss of this trust can result in the destabilisation of the entire banking sector. In this context, the DIS forms an integral component of the broader financial safety net, alongside the central bank's role as the lender of last resort and the banking regulatory and supervisory framework (Kahn & Santos, 2005).

Given the inherent instability of the banking industry and the vulnerability of the financial system to shocks, it is crucial that countries have adequate crisis prevention and management mechanisms in place (Učkar & Petrović, 2021). In this sense, Ayadi and Lastra (2010) distinguish ex-ante measures, which include regulation, supervision and business transparency, and ex-post measures that are activated in crisis situations. These include the abolition of deposit convertibility, central bank interventions, DIS, insolvency resolution procedures and implicit protection of banks or depositors in cases of systematically important institutions (too big to fail).

The DIS performs two key public functions: preventing bank runs and protecting small depositors (Barth et al., 2006). The latter function is particularly important because small depositors often lack sufficient knowledge and information to properly assess investment risks and the financial health of banks (Faulend & Kraft, 2004).

Accordingly, Carisano (1992) points out that preventing mass withdrawals from banks is the basis for justifying the existence of a DIS. Furthermore, Zolea (2023) emphasised that deposits represent a key source of funding for traditional banking, which further confirms the importance of the insurance system in preserving the stability of the banking sector.

Although DIS has an important stabilising role, its application can cause unwanted effects. Duttagupta and Cashin (2008) warn of the ambiguity of a system that, on the one hand, prevents bank runs, but, on the other, encourages moral hazard. According to Garcia (1996), adverse selection and the principal-agent relationship problem are among the main "*traps*" of deposit insurance. Moral hazard results from the reduced incentive of depositors to monitor banks and banks' tendencies to take greater risks (Cullen, 2023; Kundid Novokmet, 2015; Pierret & Howarth, 2023; Protić, 2002). Adverse selection occurs when all banks pay the same premium, regardless of risk, which favours smaller and riskier banks (Garcia, 1999; Huberdeau-Reid & Pennacchi, 2025; Suljić Nikolaj et al., 2022; Wheelock, Kumbhakar, 1995). The problem of principal-agent relationships is further exacerbated if the insurance system operates under political or sectoral influence or if there is a lack of coordination among supervisory institutions (Faulend, 2002). Although numerous studies indicate a higher risk in the behaviour of banks in systems with deposit insurance (Allen et al., 2011; Calomiris & Jaremski, 2016; Dewenter et al., 2018; Gropp & Vesala, 2004; Laeven, 2002; Lambert et al., 2017), its basic function, preventing destabilisation through withdrawal of deposits, remains crucial (Alam et al., 2021; Matutes & Vives, 1996; Martin et al., 2016; Merton, 1977). Therefore, Ayadi and Lastra (2010), and Dávila and Goldstein (2023) point out that a well-designed system, with effective supervision, strengthens confidence in the banking system.

This is confirmed by the Global Financial Crisis (GFC), which, in addition to having a pronounced debt character, also took on the characteristics of a banking crisis in a large number of EU countries (Laeven & Valencia, 2013). It was precisely in such circumstances that it was crucial to ensure the stability of deposits and preserve the confidence of depositors despite the pressures and the distrust generated by the crisis. In response to these challenges, the EU initiated the process of creating a Banking Union, the third pillar of which is a single DIS. The proposal for the EDIS Regulation, which was submitted by the European Commission in 2015 (European Council, 2024), has not yet been formally adopted as a common DIS that would replace national schemes.

The reason for this is that there is still no consensus among the Member States on a common DIS, primarily due to concerns about moral hazard, possible cross-border subsidization and uneven risk distribution (Kuznichenko et al., 2021; Single Resolution Board, 2025). For this reason, the aforementioned topic stimulates the current debate on the role and optimal design of DIS in ensuring financial stability (Arda & Dobler, 2022; Beck et al., 2022; Ferri & Pesic, 2025; Gómez Fernández-Aguado et al., 2022; Gruenberg, 2024; Tümmler, 2022).

This study is structured as follows. Section 2 provides a review of the relevant literature on DIS and its impact on the banking stability in different economic conditions. Section 3 presents the research methodology, while Section 4 describes the data set used. Section 5 is dedicated to the analysis and interpretation of the empirical results, whereas the final section presents conclusions and discusses the theoretical and practical implications of the research.

2. Literature review

Scientific research consistently shows that the effects of DIS are not unambiguous, but depend on economic conditions. In stable periods, the system often encourages moral hazard and greater risk-taking (Angkinand & Wihlborg, 2010; Brandao-Marques et al., 2013; Chesini, 2014; Chiaramonte et al., 2020; Cull et al., 2005; Dewenter et al., 2018; González, 2005; Ioannidou & Penas, 2010; Kusairi et al., 2018; Lakštutienė et al., 2011; Laeven & Levine, 2009; Ngalawa et al., 2016; Ntwaepelo, 2023; Osborne & Lee, 2001; Prabha & Wihlborg, 2014; Yilmaz & Muslumov, 2008). Conversely, in crisis periods, the DIS helps stabilise the banking system by preventing depositor panic and large-scale withdrawals (Anginer et al., 2014; Engineer et al., 2013; Hasan et al., 2017; Prabha & Wihlborg, 2014; Weiß et al., 2014).

Although Anginer et al. (2014) also emphasise that the DIS weakens market discipline in calm periods and encourages banks to take on greater risk, they also note that, in crisis conditions, it contributes to preserving stability by reducing the risk of sudden deposit outflows. The authors further point out that the negative effects in stable conditions are often stronger than the positive effects in a crisis. Similarly, Prabha and Wihlborg (2014) argue that the DIS reduces overall risk for banks in crisis periods, but, in stable conditions, it encourages risky placements and thus can increase the vulnerability of the system in the long term.

Osborne and Lee (2001) warn that negative effects in stable periods can be a trigger for future crises. In their analysis, Demirgüç-Kunt and Detragiache (2002) show that systems with a higher coverage and lower level of supervision have higher probability of banking crises. Laeven (2002) adds that the DIS reduces depositor discipline, especially in banks with lower capital, which, in turn, increases business risk. Cull et al. (2005) and González (2005) emphasise that the problem of moral hazard intensifies if the system does not differentiate premiums according to the risk taken by banks, while Wagster (2007) emphasises the connection between extended deposit insurance and an increased propensity toward risky loans. Laeven and Levine (2009) empirically confirm that banks in countries with more developed and stricter DIS are less dependent on market discipline, which increases their vulnerability to future crises.

Furthermore, Yilmaz and Muslumov (2008) and Ioannidou and Penas (2010) find that the safety of depositors weakens their motivation to supervise banks, whereas banks use the existence of a DIS as a protection against the failure of risky investments. Angkinand and Wihlborg (2010) emphasise the importance of system design (e.g. risk-sensitive premiums) in mitigating negative effects. DeLong and Saunders (2011) indicate that the lack of transparency and information asymmetry between regulators, banks and depositors further aggravates the problem of moral hazard.

Lakštutienė et al. (2011) show that the negative effects are more pronounced in countries with weaker regulatory frameworks and institutional infrastructure. Brandao-Marques et al. (2013) and Chesini (2014) confirm that the DIS can increase systemic risk in the long term if it is not accompanied by strong supervisory mechanisms. Finally, Barth et al. (2006) and Ngalawa et al. (2016) emphasise that system design, regulatory framework and institutional context decisively determine the ultimate effects of deposit insurance.

Despite the extensive literature on deposit insurance and banking stability, existing studies predominantly focus on either cross-country comparisons or single-period analyses, without explicitly distinguishing between different phases of the economic cycle. Furthermore, limited attention has been given to comparative analyses between EU and SEE countries, particularly in the context of the Global Financial Crisis.

This study aims to address this gap by providing a dynamic panel analysis of the effects of deposit insurance across pre-crisis, crisis, and post-crisis periods, using both z-score and NPL as complementary measures of bank risk. In doing so, it contributes to the literature by offering a more nuanced understanding of the cyclical implications of deposit insurance systems in different institutional environments.

Based on the above research review and the identified research gap, the following research questions are formulated:

> RQ1: *How does the deposit insurance system affect the level of bank risk before, during, and after the GFC?*

> RQ2: *To what extent do the effects of the deposit insurance system differ across the phases of the economic cycle?*

In order to provide an empirical answer to these questions, the following hypotheses are proposed. To ensure consistency between the research design and the empirical framework, the general hypothesis is further decomposed into three sub-hypotheses reflecting the distinct phases of the economic cycle analysed in this study.

> H1: *The effect of the deposit insurance system on bank risk differs depending on the phase of the economic cycle.*

> H1a: *In the pre-crisis period, the deposit insurance system is associated with higher incentives for bank risk-taking, reflecting moral hazard, adverse selection, and weaker market discipline.*

This expectation is grounded in the literature which suggests that deposit insurance weakens market discipline and encourages banks to take on additional risk in stable periods (Anginer et al., 2014; Demirgüç-Kunt & Detragiache, 2002; Laeven, 2002)

> H1b: *During the crisis period, the deposit insurance system is associated with a stabilising effect on bank risk through increased depositor confidence and reduced likelihood of systemic instability.*

Contrary to the previous hypothesis, during crisis periods, deposit insurance plays a key stabilising role by preventing depositor panic and large withdrawals (Anginer et al., 2014; Hasan et al., 2017).

> H1c: *In the post-crisis period, the deposit insurance system is associated with changes in bank risk, with effects that may differ depending on the risk measure used.*

In the post-crisis period, the effects of deposit insurance remain ambiguous, as stabilisation mechanisms coexist with renewed incentives for risk-taking (Prabha & Wihlborg, 2014).

The above hypotheses are empirically tested using a dynamic panel data approach, which allows the assessment of the impact of deposit insurance system characteristics on bank risk across different phases of the economic cycle.

3. Methodology

This study uses a dynamic panel data approach to examine the effects of deposit insurance systems (DIS) on bank risk across different phases of the economic cycle. The empirical analysis employs the two-step Arellano-Bond difference Generalised Method of Moments (GMM) estimator developed by Arellano and Bond (1991).

A dynamic panel framework is appropriate because bank risk is persistent over time, with current risk levels influenced by previous conditions. Therefore, lagged values of the dependent variable are included among the regressors. In these circumstances, conventional panel estimators may yield biased and inconsistent results due to unobserved heterogeneity, autocorrelation, and potential endogeneity between bank risk and the explanatory variables.

The Arellano-Bond difference GMM estimator addresses these issues by transforming the model into first differences and using lagged levels of endogenous variables as internal instruments. This approach helps mitigate endogeneity arising from reverse causality, omitted variable bias, and the dynamic structure of the model. In line with the recommendations of Roodman (2009), the number of instruments is restricted to avoid instrument proliferation and preserve the validity of the Hansen test.

The two-step estimator is used because it provides more efficient and consistent estimates in the presence of heteroscedasticity. In the second step, residuals from the first-step estimation are used to construct a consistent variance-covariance matrix (Adeboye & Ogunnusi, 2026; Višić & Škrabić Perić, 2011). As standard two-step GMM standard errors may be downward biased in finite samples, robust standard errors corrected according to the methodology proposed by Windmeijer (2005) are applied.

Model validity and specification are evaluated using several diagnostic tests. First, the Arellano-Bond autocorrelation test is applied to examine serial correlation in the differenced residuals. Consistent with model assumptions, first-order autocorrelation is expected, while the absence of second-order autocorrelation indicates correct model specification (Arellano & Bond, 1991).

Second, the Hansen test of over-identifying restrictions is used to assess the validity of the instrumental variables. Compared with the traditional Sargan test, the Hansen test is more robust in the presence of heteroscedasticity and is therefore considered more appropriate for the estimated models. The null hypothesis of the Hansen test assumes that the instruments are valid and uncorrelated with the error term.

Finally, the Wald test is used to examine the joint statistical significance of the explanatory variables included in the models. The combination of these diagnostic tests supports the adequacy and reliability of the estimated specifications.

The empirical analysis is conducted using the STATA software package.

3.1. Sample and model

The sample covers 34 banking systems and 1,453 credit institutions over the period 2005–2014. The data are obtained from the Orbis Bank Focus database and include EU (1,330 credit institutions) and SEE countries (123 credit institutions). The sample structure reflects the focus of this study on comparing EU Member States with non-EU SEE countries, a group that has received relatively limited attention in the existing literature. By including both groups, this study aims to address this research gap and provide a more comprehensive analysis of deposit insurance systems across different institutional environments.

Given the research hypotheses and the absence of a universally accepted definition of bank stability, it is approximated in this research by a combination of bank risk indicators. It is operationalized through two dependent variables that are common in the relevant literature (Angkinand & Wihlborg, 2006, 2010; Anginer et al., 2014; Fang et al., 2014; Forssbaeck, 2011; Fonseca & González, 2010; González, 2005; Ioannidou & Penas, 2010; Lambert et al., 2017; Laeven & Levine, 2009; Lè, 2013; Yan et al., 2014).

1. Z-score, which measures the bank's distance from insolvency (a higher score implies a lower risk appetite).
2. Share of non-performing loans (NPL) in total loans, which reflects the quality of the loan portfolio and exposure to credit risk.

In order to test the hypothesis, set out in this paper, according to which the effects of the deposit insurance system on banks' risk-taking behaviour depend on the level of general economic activity, the following models were formulated:

$$\begin{aligned} z-score_{i,t} &= a + yz-score_{i,t-1} + \beta_1 DIS * BEFORECRISIS_{i,t} + \\ &+ \beta_2 DIS * CRISIS_{i,t} + \beta_3 DIS * POSTCRISIS_{i,t} + \beta_4 lnFDPPCAPITA_{i,t} + \\ &+ \beta_5 SAVGDP_{i,t} + \beta_{11} EUSTATE_{i,t} + \varepsilon_{i,t};\ i = 1,\dots,1453,\ t = 1,\dots,10. \end{aligned} \tag{1}$$

$$NPL_{i,t} = a + yNPL_{i,t-1} + \beta_1 DIS * BEFORECRISIS_{i,t} + \beta_2 DIS * CRISIS_{i,t} + \\ + \beta_3 DIS * POSTCRISIS_{i,t} + \beta_4 lnFDPPCAPITA_{i,t} + \beta_5 SAVGDP_{i,t} + \\ + \beta_{11} EUSTATE_{i,t} + \varepsilon_{i,t};\ i = 1,\ldots,1453,\ t = 1,\ldots,10. \quad (2)$$

To examine the implications of the deposit insurance system on bank risk across different phases of the economic cycle, the key explanatory variables are specified as interaction terms between period-specific dummy variables and the deposit insurance variable (DIS). In the empirical model, DIS is operationalised as the natural logarithm of the deposit insurance coverage amount.

Specifically, three interaction variables are constructed: (DIS x PRECRISIS) for the pre-crisis period (2005–2007), (DIS x CRISIS) for the crisis period (2008–2012), and (DIS x POSTCRISIS) for the post-crisis period (2013–2014). These variables capture the period-specific effects of deposit insurance on bank risk, allowing the impact of deposit insurance to vary across different phases of the economic cycle. Definitions and descriptions of all variables included in the empirical models are reported in Table 4 in the Appendix.

In addition, dummy variables (PRECRISIS, CRISIS, POSTCRISIS) are included in alternative model specifications to account for the direct effects of macroeconomic conditions on bank risk. It is important to distinguish between these dummy variables, which reflect general economic conditions, and the interaction terms, which measure how the effect of deposit insurance changes across different periods. This specification follows the empirical approach of Anginer et al. (2014) and Prabha and Wihlborg (2014), enabling a more nuanced assessment of the cyclical implications of deposit insurance systems. However, unlike these studies, which define the crisis period as 2007–2009 due to their broader global sample, this study identifies the crisis period as 2008–2012 based on macroeconomic indicators such as GDP growth and GDP per capita within the observed countries.

In addition to the baseline specification, further model variations are estimated to address potential multicollinearity and to test the robustness of the results. These alternative specifications include additional characteristics of the deposit insurance system, such as the ratio of coverage amount to GDP per capita, the mode of system administration, and the type of premium, as well as macroeconomic control variables. Dummy variables are also included to indicate the pre-crisis, crisis, and post-crisis periods. The models are estimated using z-score and NPL as dependent variables.

$$z-score_{i,t} = \alpha + \gamma z-score_{i,t-1} + \beta_1 PRECRISIS_{i,t} + \beta_2 limgdp_{i,t} + \\ + \beta_3 PREMIA_{i,t} + \beta_4 ADMINISTRATION_{i,t} + \beta_5 lnGDPPCAPITA_{i,t} + \\ + \beta_{11} SAVGDP_{i,t} + \beta_{12} EUSTATE_{i,t} + \varepsilon_{it};\ i = 1,...,1453,\ t = 1,\ldots,10. \quad (3)$$

$$z-score_{i,t} = \alpha + \gamma z-score_{i,t-1} + \beta_1 CRISIS_{i,t} + \beta_2 limgdp_{i,t} + \beta_3 PREMIA_{i,t} + \\ + \beta_4 ADMINISTRATION_{i,t} + \beta_5 lnGDPPCAPITA_{i,t} + \beta_{11} SAVGDP_{i,t} + \\ + \beta_{12} EUSTATE_{i,t} + \varepsilon_{i,t};\ i = 1,...,1453,\ t = 1,\ldots,10. \quad (4)$$

$$z-score_{i,t} = \alpha + \gamma z-score_{i,t-1} + \beta_1 POSTCRISIS_{i,t} + \beta_2 limgdp_{i,t} + \\ + \beta_3 PREMIA_{i,t} + \beta_4 ADMINISTRATION_{i,t} + \beta_5 lnGDPPCAPITA_{i,t} + \\ + \beta_{11} SAVGDP_{i,t} + \beta_{12} EUSTATE_{i,t} + \varepsilon_{i,t};\ i = 1,...,1453,\ t = 1,\dots,10. \quad (5)$$

$$NPL_{i,t} = \alpha + \gamma NPL_{i,t-1} + \beta_1 PRECRISIS_{i,t} + \beta_2 limgdp_{i,t} + \beta_3 PREMIA_{i,t} + \\ + \beta_4 ADMINISTRATION_{i,t} + \beta_5 lnGDPPCAPITA_{i,t} + \beta_{11} SAVGDP_{i,t} + \\ + \beta_{12} EUSTATE_{i,t} + \varepsilon_{i,t};\ i = 1,...,1453,\ t = 1,\dots,10. \quad (6)$$

$$NPL_{i,t} = \alpha + \gamma NPL_{i,t-1} + \beta_1 CRISIS_{i,t} + \beta_2 limgdp_{i,t} + \beta_3 PREMIA_{i,t} + \\ + \beta_4 ADMINISTRATION_{i,t} + \beta_5 lnGDPPCAPITA_{i,t} + \beta_{11} SAVGDP_{i,t} + \\ + \beta_{12} EUSTATE_{i,t} + \varepsilon_{i,t};\ i = 1,...,1453,\ t = 1,\dots,10. \quad (7)$$

$$NPL_{i,t} = \alpha + \gamma NPL_{i,t-1} + \beta_1 POSTCRISIS_{i,t} + \beta_2 limgdp_{i,t} + \beta_3 PREMIA_{i,t} + \\ + \beta_4 ADMINISTRATION_{i,t} + \beta_5 lnGDPPCAPITA_{i,t} + \beta_{11} SAVGDP_{i,t} + \\ + \beta_{12} EUSTATE_{i,t} + \varepsilon_{i,t};\ i = 1,...,1453,\ t = 1,\dots, 10. \quad (8)$$

The period encompassing the GFC is particularly relevant for investigating the impact of DIS, as this crisis exposed the structural weaknesses of banking systems and regulatory frameworks at the time. In such conditions, the DIS serves as a key mechanism for limiting bank panics and preserving confidence. The crisis period therefore provides insight into the stabilising role of DIS during financial instability, while the pre- and post-crisis periods highlight potential moral hazard and risk-taking incentives associated with the financial safety net. This sample therefore enables a clearer comparison of the effects of DIS at different stages of the cycle and under varying financial conditions, which would not be possible in stable or single-phase periods.

In contrast, the same period also represents a limitation of this paper. Although the time frame 2005-2014 covers the pre-crisis, crisis, and post-crisis periods, it does not include subsequent regulatory changes, such as the full implementation of Basel III, the establishment of the SRM, and more recent reforms at EU level. Therefore, future research should focus on the period after 2014 to examine the effects of DIS in the new regulatory and institutional environment.

3.2. Descriptive statistics and correlation

Descriptive statistics show that the dummy variables DIS x PRECRISIS, DIS x CRISIS, and DIS x POSTCRISIS have lower standard deviations among the observed credit institutions. This is due to the varying number of institutions observed from countries included in the research sample and the differences in DIS characteristics across countries. Following the descriptive statistics, the results of the econometric model are preceded by an analysis of the correlation among the observed independent variables, as a high correlation between individual variables indicates multicollinearity, which distorts the significance of the estimated parameters. Pearson's correlation coefficient ranges from -1 to 1 and indicates the direction and strength of the linear statistical correlation between variables. A value of 0 indicates no correlation between the observed variables, positive values indicate a consistent increase, and negative values indicate that as one variable increases, the other decreases. Complete correlation is observed at the extreme values of the coefficient. According to Field (2009) and Lovrić (2005), multicollinearity may be present when correlation coefficients between pairs of independent variables exceed 0.8 or are less than -0.8. The correlation matrix preceding the dynamic panel analysis is presented below.

Table 1a: Descriptive statistics for model variables with z-score and NPL as dependent variables

Variable		Arithmetic mean	Standard deviation	Minimum value	Maximum value	Number of observations
z-score	overall	2.876875	1.557244	-4.66531	8.902474	N = 11,433
	between		1.503968	-2.808699	6.818049	n = 1,368
	within		0.38116303	-2.801569	6.825821	T = 8.35746
NPL	overall	8.128249	10.76065	-4.35	108.71	N = 5,369
	between		10.0161	0.0257143	104.885	n = 1,126
	within		5.988975	-32.49318	88.777	T = 4.76821
lnlimit	overall	10.94649	0.7570291	7.846199	11.56637	N = 13,576
	between		0.3990982	8.006368	11.52912	n = 1,453
	within		0.650518	8.977107	12.07456	T = 9.34343
ADMIN-ISTRA-TION	overall	0.1783202	0.3827953	0	1	N = 14,502
	between		0.3367885	0	1	n = 1,453
	within		0.1817097	-0.5216798	0.8783202	T = 9.98073
PREMIA	overall	0.376224	0.484454	0	1	N = 14,502
	between		0.2910743	0	1	n = 1,453
	within		0.3880854	-0.323776	1.076224	T = 9.98073
lnGDPP-CAPITA	overall	10.07438	0.6893274	7.49599	11.99526	N = 14,530
	between		0.6776451	7.777148	11.27312	n = 1,453
	within		0.1274905	9.637592	12.07964	T = 10
GDS	overall	22.87887	8.469526	-13.8	52.8	N = 14,526
	between		8.294994	-5.56	50.62	n = 1,453
	within		1.775576	13.37887	31.24887	T = 9.99725
EUSTATE	overall	0.9227805	0.2669487	0	1	N = 14,530
	between		0.2530475	0	1	n = 1,453
	within		0.0852539	0.1227805	1.72278	T = 10

Variable		Arithmetic mean	Standard deviation	Minimum value	Maximum value	Number of observations
NOEUSTATE	overall	0.0772195	0.2669487	0	1	N = 14,530
	between		0.2530475	0	1	n = 1,453
	within		0.852539	-0.7227805	1.8772195	T = 10

Source: Author's calculations using STATA 13.0

Table 1b: Descriptive statistics for the deposit insurance system – related independent variables by general economic activity (pre-crisis, crisis, and post-crisis periods)

Variable		Arithmetic mean	Standard deviation	Minimum value	Maximum value	Number of observations
PRECRISIS	overall	0.3	0.4582733	0	1	N = 14,530
	between		0	0.3	0.3	n = 1,453
	within		0.4582733	0	1	T = 10
CRISIS	overall	0.5	0.5000172	0	1	N = 14,530
	between		0	0.5	0.5	n = 1,453
	within		0.5000172	0	1	T = 10
POSTCRISIS	overall	0.2	0.4000138	0	1	N = 14,530
	between		0	0.2	0.2	n = 1,453
	within		0.400138	0	1	T = 10
DIS * PRECRISIS	overall	3.023516	4.64048	0	11.54531	N = 14,530
	between		0.2428861	0.3	3.463593	n = 1,453
	within		4.634123	-0.4400772	12.58254	T = 10
DIS * CRISIS	overall	4.988742	5.557795	0	11.56049	N = 14,530
	between		0.8748512	0.5	5.762941	n = 1,453
	within		5.488552	-0.7741993	13.89909	T = 10
DIS * POSTCRISIS	overall	2.28118	4.572569	0	11.56637	N = 14,530
	between		0.1073507	1.251293	2.308037	n = 1,453
	within		4.571308	-0.0268574	12.54282	T = 10
limgdp	overall	0.8872844	0.7690834	-2.028799	2.967707	N = 13,576
	between		0.5048752	-0.2805814	2.231066	n = 1,453
	within		0.5789886	-2.044542	1.95216	T = 9.34343

Source: Author's calculations using STATA 13.0

The correlation matrix displays only correlation coefficients that are statistically significant at the 5% level (95% confidence level), with an asterisk indicating coefficients significant at the 1% level (99% confidence level). Based on the reported correlation coefficients, it is possible to identify pairs of independent variables that could potentially cause a multicollinearity problem. According to the adopted threshold, defined as a positive or negative correlation greater than 0.8, no variable exceeds the threshold of 0.8 or -0.8. The correlation between gross domestic product per capita (lnGDPPCAPITA) and EU membership (EUSTATE) is 0.7091, indicating a positive association between GDP per capita and EU membership; that is, higher GDP per capita is observed among EU members. The results for the variable representing non-EU membership (NOEUSTATE) are the same as those for the membership variable (EUSTATE), but with the opposite sign. Therefore, the correlation between NOEUSTATE and lnGDPPCAPITA is -0.7091. A positive correlation of 0.7159 was recorded between the GDS variable, which represents the interest rate on deposits adjusted for inflation, and the GDP per capita variable (lnGDPPCAPITA). Additionally, the correlation between lnGDPPCAPITA and SAVEGDP is 0.72, which implies that increases in GDP per capita are accompanied by increases in the savings rate. Among other pairs of independent variables, the correlation coefficients are not at levels that could lead to multicollinearity.

Table 2: Correlation matrix of dependent and independent model variables

	z-score	NPL	PRECRISIS	CRISIS	POSTCRISIS	DISxPRECRISIS	DISxCRISIS	DISxPOSTCRISIS	limgdp	ADMINISTRATION	PREMIA	lnGDPPCAPITA	SAVGDP	EUSTATE	NOEUSTATE
z-score	1														
NPL		1													
PRECRISIS		-0.1380*	1												
CRISIS				1											
POSTCRISIS	0.0302*	0.0883*			1										
DISxPRECRISIS		-0.1407*				1									
DISxCRISIS	0.0264*						1								
DISxPOSTCRISIS	0.0327*	0.0779*						1							
limgdp	-0.2355*	0.3228*	-0.6737*	0.4213*	0.2542*	-0.6598*	0.4216*	0.2527*	1						
ADMINISTRATION	-0.2205*		0.0514*	-0.0334*	-0.0172	0.0724*		-0.0184	-0.0404*	1					
PREMIA	-0.0837*		0.4612*	-0.3027*	-0.1498*	0.4464*	-0.2170	-0.1481*	-0.2538*	-0.1212*	1				
lnGDPPCAPITA	0.2875*	-0.3203*	-0.1001*	0.0323*	0.0743*	-0.0684*		0.0825*	-0.4686*	0.1233*	-0.1617*	1			
SAVGDP	0.1387*	-0.2544*	0.0294*	-0.0379*		0.0470	-0.0634*	0.0193	-0.4156*	0.1812*	-0.1267*	0.7159*	1		
EUSTATE	0.1807*	-0.2420*	-0.0385*		0.0402*			0.0516*	-0.1866*		0.0618*	0.7091*	0.5508*	1	
NOEUSTATE	-0.1807*	0.2420*	0.0385*		-0.0402*			-0.0516*	0.1866*		-0.0618*	-0.7091*	-0.5508*		1

Note: * indicates statistical significance at the level of 1%; bolded values suggest a correlation to 0.8.

** Empty cells in the correlation matrix do not indicate the absence of a relationship between variables, but rather correlations that are not statistically significant at the 5% level and are therefore not relevant for assessing multicollinearity in the model.

Source: Author's calculations using STATA 13.0

The correlation matrix is followed by the estimation of the dynamic panel model using the two-step Arellano-Bond (AB) estimator.

4. Empirical data

This chapter presents the results of the dynamic panel analysis examining the implications of DISs for bank risk at different stages of the economic cycle. The empirical models are estimated using a two-step Arellano-Bond GMM estimator, which accounts for the dynamic nature of bank risk indicators and the potential endogeneity of the explanatory variables. Tables 3a to 3d present the estimated coefficients of the models, in which the dependent variables include the z-score and the share of non-performing loans in total loans (NPL). The models differ in how they incorporate the DIS characteristics: some specifications use interaction variables for the pre-crisis, crisis, and post-crisis periods, while alternative models use dummy variables indicating the phases of economic activity. The models also include variables for EU membership and non-membership to control for institutional differences across the observed countries.

Table 3a: Overview of the panel analysis results on the impact of deposit insurance systems on bank risk by general economic activity (including EU membership)

Dependent variables	z-score	NPL
Independent variables		
Lagged dependent variable	0.544*** (0.076)	0.417** (0.163)
DIS * PRECRISIS	0.013*** (0.0014)	-0.087 (0.090)
DIS * CRISIS	0.142*** (0.016)	0.124* (0.073)
DIS * POSTCRISIS	0.100*** (0.0014)	0.159** (0.076)
lnGDPPCAPITA	0.137** (0.057)	-5.793** (2.393)
SAVGDP	0.005* (0.003)	0.036 (0.029)
EUSTATE	-0.201*** (0.072)	1.644 (1.311)
constant	-1.141 (0.574)	58.670** (23.568)
Z(1)	-6.432***	-1.805*
Z(2)	0.103	-0.295
Wald test	323.35***	64.04***
No. of instruments	43	43
No. of observations	8,503	3,107
No. of banks	1,325	816
Stage	2	2

Note: *,**,*** – level of significance at 10%, 5% and 1%

Source: Author's calculations using STATA 13.0

Table 3b: Overview of the panel analysis results on the impact of deposit insurance systems on bank risk by general economic activity (including EU membership)

Dependent variables	z-score	z-score	z-score	NPL	NPL	NPL
Independent variables						
Lagged dependent variable	0.516*** (0.612)	0.473*** (0.073)	0.524*** (0.074)	0.364* (0.190)	0.278* (0.174)	0.281* (0.169)
PRECRISIS	0.129*** (0.024)			-0.256 (0.627)		
CRISIS		-0.033*** (0.010)			0.439** (0.199)	
POSTCRISIS			0.018* (0.011)			0.540*** (0.196)
limgdp	0.091*** (0.154)	0.056*** (0.013)	0.042*** (0.121)	2.147*** (0.561)	2.748*** (0.441)	2.482*** (0.400)
PREMIA	0.735*** (0.228)	0.060*** (0.023)	0.061** (0.024)	0.766** (0.339)	0.995** (0.298)	0.889*** (0.264)
ADMINISTRA-TION	-0.473 (0.035)	0.034 (0.031)	0.058* (0.032)	-0.617 (0.464)	-1.067** (0.433)	-0.847** (0.415)
lnGDPPCAPITA	0.288*** (0.048)	0.168*** (0.040)	0.159*** (0.044)	-2.332 (2.419)	-1.702 (1.975)	-2.339 (2.034)
SAVGDP	0.004 (0.003)	0.007*** (0.002)	0.008*** (0.003)	0.009 (0.023)	0.026 (0.025)	0.035 (0.026)
EUSTATE	-0.224*** (0.065)	-2.242*** (0.067)	-0.218*** (0.066)	0.983 (1.227)	0.202 (1.237)	0.241 (1.222)
constant	-1.561*** (0.429)	-0.239 (0.411)	-0.320 (0.471)	24.049 (23.747)	18.217 (19.313)	24.265 (19.882)
Z(1)	-6.809***	-6.259***	-6.435***	-1.260	-0.949	-0.992
Z(2)	-1.924	-0.331	-0.176	0.084	0.215	0.187
Wald test	278.74***	290.81***	261.90***	62.96***	59.57***	66.83***
No. of instruments	44	44	44	44	44	44
No. of observa-tions	7,218	7,218	7,218	2,959	2,959	2,959
No. of banks	1,321	1,321	1,321	811	811	811
Stage	2	2	2	2	2	2

Note: *,**,*** – level of significance at 10%, 5% and 1%

Source: Author’s calculations using STATA 13.0

Table 3c: Overview of the panel analysis results on the impact of deposit insurance systems on bank risk by general economic activity (including non-EU membership)

Dependent variables	z-score	NPL
Independent variables		
Lagged dependent variable	0.544*** (0.076)	0.417** (0.163)
DIS * PRECRISIS	0.013*** (0.0014)	-0.087 (0.090)
DIS * CRISIS	0.142*** (0.016)	0.124* (0.073)
DIS * POSTCRISIS	0.100*** (0.0014)	0.159** (0.076)
lnGDPPCAPITA	0.137** (0.057)	-5.793** (2.393)
SAVGDP	0.005* (0.003)	0.036 (0.029)
NOEUSTATE	0.201*** (0.072)	-1.644 (1.311)
constant	-0.342 (0.572)	60.314** (23.729)
Z(1)	-6.432***	-1.805*
Z(2)	0.103	-0.295
Wald test	323.35***	64.04***
No. of instruments	43	43
No. of observations	8,503	3,107
No. of banks	1,325	816
Stage	2	2

Note: *,**,*** – level of significance at 10%, 5% and 1%

Source: Author's calculations using STATA 13.0

Table 3d: Overview of the panel analysis results on the impact of deposit insurance systems on bank risk by general economic activity (including non-EU membership)

Dependent variables	z-score	z-score	z-score	NPL	NPL	NPL
Independent variables						
Lagged dependent variable	0.516*** (0.612)	0.473*** (0.073)	0.524*** (0.074)	0.364* (0.190)	0.278* (0.174)	0.281* (0.169)
PRECRISIS	0.129*** (0.024)			-0.256 (0.627)		
CRISIS		-0.033*** (0.010)			0.439** (0.199)	
POSTCRISIS			0.018* (0.011)			0.540*** (0.196)
limgdp	0.091*** (0.154)	0.056*** (0.013)	0.042*** (0.121)	2.147*** (0.561)	2.748*** (0.441)	2.482*** (0.400)
PREMIA	0.745*** (0.228)	0.060*** (0.023)	0.061** (0.024)	0.766** (0.339)	0.995** (0.298)	0.889*** (0.264)
ADMINISTRA-TION	-0.473 (0.035)	0.034 (0.031)	0.058* (0.032)	-0.617 (0.464)	-1.067** (0.433)	-0.847** (0.415)
lnGDPPCAPITA	0.288*** (0.048)	0.168*** (0.040)	0.159*** (0.044)	-2.332 (2.419)	-1.702 (1.975)	-2.339 (2.034)
SAVGDP	0.004 (0.003)	0.007*** (0.002)	0.008*** (0.003)	0.009 (0.023)	0.026 (0.025)	0.035 (0.026)
NOEUSTATE	0.224*** (0.065)	2.242*** (0.067)	0.218*** (0.066)	-0.983 (1.227)	-0.202 (1.237)	-0.241 (1.222)
constant	-1.785*** (0.430)	-0.481 (0.406)	-0.539 (0.465)	25.032 (23.801)	18.419 (19.360)	24.506 (19.854)
Z(1)	-6.809***	-6.259***	-6.435***	-1.260	-0.949	-0.992
Z(2)	-1.924	-0.331	-0.176	0.084	0.215	0.187
Wald test	278.74***	290.81***	261.90***	62.96***	59.57***	66.83***
No. of instruments	44	44	44	44	44	44
No. of observa-tions	7,218	7,218	7,218	2,959	2,959	2,959
No. of banks	1,321	1,321	1,321	811	811	811
Stage	2	2	2	2	2	2

Note: *,**,*** – level of significance at 10%, 5% and 1%

Source: Author's calculations using STATA 13.0

The coefficients of the lagged dependent variable are positive and statistically significant in all model specifications, confirming inertia in the movement of bank risk indicators and supporting the use of the dynamic panel approach.

Variables describing the DIS characteristics are statistically significant in presented models, with the intensity and direction of the estimated effects varying according to the dependent variable and the economic period observed. The models also include macroeconomic control variables, such as gross domestic product per capita (lnGDPPCAPITA), the share of savings in GDP (SAVGDP), and the ratio of the amount of protection to GDP per capita (limGDP), all of which have statistically significant coefficients in several specifications. Institutional characteristics of DIS, including the administration of the system (ADMINISTRATION), the premium structure (PREMIA), and variables indicating membership or non-membership in the EU (EUSTATE and NOEUSTATE), are included to capture differences in the regulatory and institutional environment across the sample countries.

The Arellano–Bond test confirms the presence of first-order autocorrelation and the absence of second-order autocorrelation, supporting the correct specification of the model. The Wald test indicates the joint statistical significance of the explanatory variables.

A detailed interpretation of the results obtained and their connection with theoretical assumptions and relevant empirical literature is presented in the next section.

5. Results and discussion

The results of the panel analysis of the implications of DIS on bank risk in different economic periods show differentiated effects. It is important to note that the interpretation of coefficients differs depending on the risk measure used. An increase in the z-score indicates lower bank risk, while an increase in the share of non-performing loans (NPL) reflects higher credit risk. Therefore, the same coefficient sign may imply different risk implications across these two measures. The different behaviour of the z-score and NPL indicators may also reflect the fact that these variables capture different dimensions of bank risk. While the z-score is a broader forward-looking indicator of bank stability that incorporates profitability, leverage, and earnings volatility, NPL primarily reflects realised credit risk and tends to adjust more slowly to changes in macroeconomic conditions. Similar findings on the heterogeneous behaviour of financial risk indicators are reported by Svoboda et al. (2025), who show that different financial stability and risk assessment models may produce systematically different classifications depending on the risk dimension considered.

In the pre-crisis period (2005–2007), the DIS × PRECRISIS variable shows a positive and statistically significant relationship with the z-score, indicating a reduction in overall bank risk. In contrast, the relationship with NPL is negative but statistically insignificant, suggesting that credit risk dynamics were less sensitive to deposit insurance coverage during this period of economic expansion.

During the crisis period (2008–2012), the DIS × CRISIS variable exhibits a positive and significant relationship with the z-score, indicating a stabilising effect of deposit insurance on bank risk. However, the relationship with NPL is also positive and significant, reflecting an increase in credit risk. This finding suggests that deposit insurance primarily operates through the liability side of bank balance sheets by stabilising depositor behaviour and reducing liquidity pressures, with only a limited capacity to affect the quality of previously extended loans. These dynamics in bank stability are also illustrated in Graph 1 presented in the Appendix.

In the post-crisis period (2013–2014), the DIS × POSTCRISIS variable shows a positive and significant relationship with both the z-score and NPL. This suggests that while overall bank stability improves, as reflected in higher z-scores, credit risk remains elevated. These findings indicate that the stabilising effects of deposit insurance persist, but are accompanied by continued vulnerabilities in loan quality. The movement of NPL ratios across the observed period is presented in Graph 2 in the Appendix.

Overall, these results confirm that the effects of deposit insurance are not uniform across different dimensions of bank risk. While the system effectively reduces insolvency risk during periods of financial stress, it does not fully eliminate incentives for excessive risk-taking nor does it prevent the accumulation of credit risk, particularly after crisis periods. The findings therefore support the moral hazard hypothesis, which suggests that stronger deposit protection may weaken market discipline and encourage greater risk-taking during periods of economic stability.

Control variables such as Gross Domestic Product per capita (lnGDPPCAPITA) show a positive and significant relationship with the z-score and a negative and significant relationship with NPL, confirming that a higher level of economic development reduces bank risk. The savings ratio (SAVGDP) is positive and significant only with the z-score, meaning that an increase in savings reduces risk, primarily in periods of stability. EU membership (EUSTATE) is associated with higher risk, while non-membership (NOEUSTATE) shows the opposite effect, partly reflecting different experiences of banking crises within the EU. The ADMINISTRATION variable suggests that private DIS reduce risk, which is consistent with empirical research indicating that private models can have a disciplining effect ((Brandao-Marques et al., 2013; Calomiris, 1990; Demirgüç-Kunt & Detragiache, 2002; Demirgüç-Kunt et al., 2007; Garcia, 1996, 1999). The relationship between deposit insurance premiums (PREMIA) and risk measures is also positive and significant, confirming that more fairly structured premiums can reduce risk measured by the z-score, but at the same time increase exposure to credit risk (NPL).

The results indicate that the DIS contributed to reducing bank risk during the crisis period, as reflected in the higher z-score values, thereby supporting its stabilising function. However, the same system could not prevent the increase in NPLs, which are the result of the pre-crisis credit expansion and macroeconomic deterioration. This suggests that the stabilising effect of deposit insurance may be insufficient to fully offset the long-term consequences of excessive credit growth. From a regulatory perspective, these findings imply that deposit insurance alone cannot guarantee banking stability unless accompanied by effective supervision, prudent lending standards, and mechanisms limiting excessive risk-taking. Consistent with the research of Anginer et al. (2014), Anginer and Demirgüç-Kunt (2018), and Prabha and Wihlborg (2014), these findings support the hypothesis that the implications of deposit insurance schemes for bank risk vary across phases of the economic cycle. Overall, the findings provide empirical support for the hypothesis that the effects of deposit insurance are cyclical and depend on the broader macroeconomic environment, as well as on the specific dimension of bank risk being examined.

6. Conclusions

The aim of this paper was to examine the effects of DIS on bank risk across different phases of the economic cycle, with particular emphasis on the periods before, during, and after the GFC. Using a dynamic panel analysis on a sample of EU and SEE countries for the period 2005 to 2014, the relationship between the characteristics of DIS and two measures of bank risk, the z-score and the share of non-performing loans in total loans, was analysed. The results confirm that the effects of DIS on bank risk are not unambiguous, but largely depend on the phase of the economic cycle. During the financial crisis, the DIS played a pronounced stabilising role, reflected in reduced risk as measured by the z-score. This finding highlights the importance of DIS in preventing depositor panic and maintaining confidence in the banking system during periods of increased financial uncertainty.

In contrast, the results also indicate the limited capacity of the DIS to influence banks' credit risk. During the crisis and in the post-crisis period, the increase in the level of deposit protection did not prevent the increase in non-performing loans, confirming that credit risk is largely a consequence of pre-crisis credit expansion and deteriorating macroeconomic conditions. This demonstrates that, although a DIS is crucial for maintaining the stability of the deposit base, it cannot independently address the structural weaknesses of banks' credit portfolios.

During the pre-crisis and post-crisis periods, increased risk appetite was observed, indicating the presence of moral hazard and weaker market discipline in a stable economic environment. Furthermore, the results highlight the importance of the design of DIS, with features such as the level of protection relative to GDP, the premium structure, and system administration exerting a significant influence on bank behaviour and the degree of risk assumed.

The findings of this study add to the existing literature by providing empirical evidence on the cyclical effects of DIS on bank risk in Europe. The main contribution of the paper is its comparative analysis of EU and SEE countries, highlighting differences in institutional and regulatory environments that influence the effectiveness of DIS.

The results have important implications for ongoing debates on further development of the Banking Union and the creation of a common EDIS. The findings indicate that an increase in the level of deposit protection can have positive effects during crises, while the long-term stability of the banking system requires a carefully designed scheme that protects depositors yet limits incentives for excessive risk-taking.

The limitations of this paper relate mainly to the time frame of the analysis, which ends in 2014 and does not cover subsequent regulatory changes, such as the full implementation of Basel III, the establishment of the Single Resolution Mechanism (SRM), and recent reforms at EU level. Future research should examine more recent periods to assess whether changes in the regulatory framework have altered the effects of DIS on bank risk, and provide a deeper analysis of the interaction between DIS, supervision, and other elements of the financial safety net. These findings support hypotheses H1a–H1c, confirming the cyclical nature of deposit insurance effects.

Note: This manuscript is based on the author's doctoral thesis: "*Deposit insurance system in the function of banking stability*".

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Sustav osiguranja depozita u različitim financijskim uvjetima

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Sažetak

Sustav osiguranja depozita predstavlja jednu od ključnih sastavnica financijske stabilnosti jer štiti deponente i smanjuje rizik od navale na banke (engl. bank run). Međutim, njegov utjecaj na bankovni rizik nije jednoznačan te ovisi o fazi gospodarskog ciklusa. Cilj ovoga rada jest ispitati različite učinke sustava osiguranja depozita na stabilnost banaka prije, tijekom i nakon financijske krize. Analiza se temelji na dinamičkom panel-modelu procijenjenom primjenom Arellano-Bondova GMM procjenitelja na uzorku zemalja Europske unije i odabranih zemalja jugoistočne Europe, u razdoblju od 2005. do 2014. godine. Bankovna stabilnost mjerena je z-score pokazateljem i udjelom nenaplativih kredita (engl. non-performing loan – NPL). Rezultati pokazuju da sustav osiguranja depozita tijekom krize ima stabilizirajući učinak jer ublažava rizik nestabilnosti bankovnog sustava. S druge strane, u razdobljima prije i nakon krize dolazi do povećane sklonosti preuzimanju rizika, što upućuje na prisutnost moralnog hazarda. U skladu s rezultatima ovog istraživanja i iskustvima stečenima tijekom globalne financijske krize, u Europskoj uniji nastavljaju se rasprave o dovršetku trećeg stupa Bankovne unije, odnosno zajedničkog europskog sustava osiguranja depozita (engl. European Deposit Insurance Scheme – EDIS). Iako među državama članicama još nije postignut konsenzus zbog razlika u obilježjima nacionalnih financijskih sustava, EDIS se smatra instrumentom koji bi mogao pridonijeti većoj koordinaciji i otpornosti bankarskog sektora u budućim krizama.

Ključne riječi: *bankovna stabilnost, dinamička panel-analiza, moralni hazard, bankovna unija*

JEL klasifikacija*:C33, E32, G21*

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Appendix

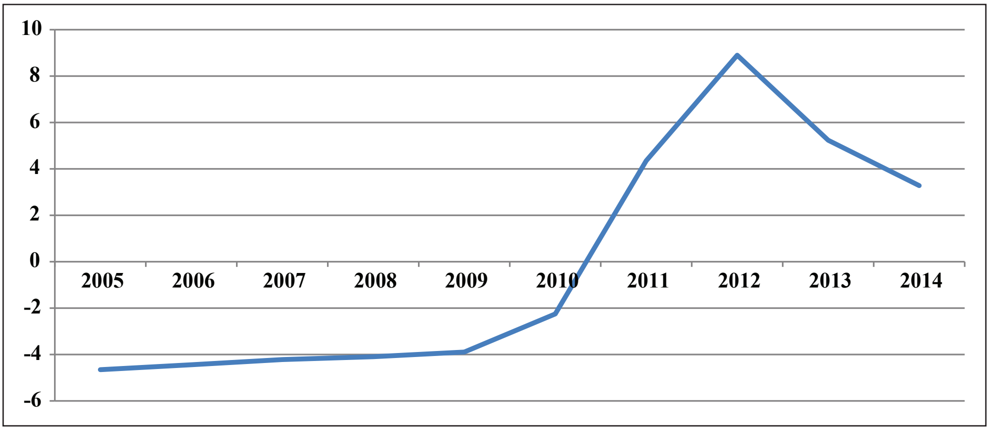
Table 4: List of variables

Name of variable	Label	Explenation	Source
Dependent variables			
Bank risk indcators			
z-score	z-score	Measure of bank stability z-score = [E(ROA) + CAP] / σROA the natural logarithm of the z-score	Authors' calculation by rolling window analysis for 3 years according to data on return on assets and the ratio of capital to total assets, Orbis Bank Focus Database
Non-performing loans/total loans	NPL	Share of non-performing loans in total loans (%) Deposit volatility indicators	Orbis Bank Focus Database
Independent variables			
Characteristics of the deposit insurance system			
Limit/GDP	limgdp	Natural logarithm of the ratio of the protection amount provided by the deposit insurance system to GDP per capita	Authors' calculations based on Schich (2008); CESifo DICE Report 4/2008, 4/2011; Demirguc-Kunt et al. (2014); and data from deposit insurance institutions, central banks, and the WDI
Management of the deposit insurance system	ADMINIS-TRATION	Dummy variable: 0 – state 1 – private way of managing the deposit insurance system	Schich (2008); CESifo DICE Report 4/2008, 4/2011; Demirguc-Kunt, et al. (2014); Data-from deposit insurance institutions and central banks
Premia	PREMIA	Dummy variable: 0 – undifferentiated premium according to the credit institution's risk 1 – differentiated (fair premium) according to risk	Schich (2008); CESifo DICE Report 4/2008, 4/2011; Demirguc-Kunt, et al. (2014); Data from deposit insurance institutions and central banks

Name of variable	Label	Explenation	Source
Independent variables			
Characteristics of the deposit insurance system			
Characteristics of the deposit insurance system before the crisis	DIS x PRE-CRISIS	the product of the amount of protection and a dummy variable indicating the period before the crisis	Authors' calculation
Characteristics of the deposit insurance system during the crisis	DIS x CRISIS	the product of the amount of protection and a dummy variable indicating the crisis period	Authors' calculation
Characteristics of the deposit insurance system after the crisis	DIS x POST-CRISIS	the product of the amount of protection and a dummy variable indicating the period after the crisis	Authors' calculation
Indicators of economic conditions			
Pre-crisis period	PRECRISIS	Dummy variable: 1 - pre-crisis period (2005 to 2007) 0 - periods not related to the pre-crisis period	Laeven and Valencia (2013)
A period of crisis	CRISIS	Dummy variable: 1 - crisis period (2008-2012) 0 - periods not related to the crisis period	Laeven and Valencia (2013)
Post-crisis period	POSTCRISIS	Dummy variable: 1 - post-crisis period (2013-2014) 0 - periods not related to the post-crisis period	Laeven and Valencia (2013)
EU membership	EUSTATE	Dummy variable: 1 – EU members 0 – SEE countries	
Non-EU membership	NOEUSTATE	Dummy variable: 1 – SEE countries 0 – EU members	
Macroeconomic indicators			
GDP per capita	GDPPCAP-ITA	The natural logarithm of the annual amount in thousands of dollars, converted into thousands of euros	World Bank - World Development Indicators [WDI] (2026a)
Savings rate	SAVGDP	Gross domestic savings (% of GDP)	World Bank - World Development Indicators [WDI] (2026b)

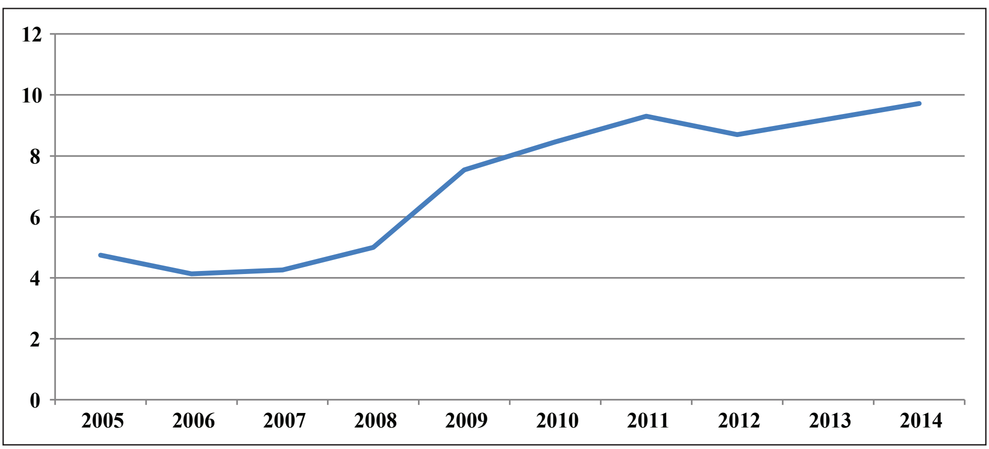
Source: Author's representation

Graph 1: Movement of the annual average of the natural logarithm of the z-score of credit institutions from EU and SE Europe countries, in the period from 2005 to 2014



Source: Author's calculations based on data from Orbis Bank Focus Database

Graph 2: Movement of the annual average of the share of non-performing loans in total loans (NPL) of credit institutions from EU and SE Europe countries, in the period from 2005 to 2014 (in %)



Source: Author's calculations based on data from Orbis Bank Focus Database

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The Impact of Lifelong Learning on Labor Market Outcomes Amid Population Aging: A Systematic Literature Review*

Ana Štambuk[1]

Abstract

Improving the position of older workers in the labor market is often linked to the importance of lifelong learning. This study aims to explore the outcomes of lifelong learning for older workers in the labor market by conducting a systematic literature review of articles based on the European Union countries, published between 2010 and 2024, and indexed in the WoS and Scopus databases. The influence of lifelong learning on labor market outcomes was grouped into five clusters: employability, exit from employment, earnings, job satisfaction, and job performance. Across all clusters, except job performance, the direction of the relationship between lifelong learning and labor market outcomes is not straightforward. Regarding employability, lifelong learning does not consistently increase it, but it often helps buffer the negative effects of aging. Results regarding exit from employment are also inconclusive, but the relationship tends to be more positive than negative. As for earnings, lifelong learning shows a positive effect, yet the effect may weaken with age or even turn negative. Job satisfaction appears to benefit from lifelong learning, but the effect is not always significant, and negative effects may occur, for example, when workers who do not want to pursue lifelong learning feel pressured, or when they perceive it as too late to gain meaningful benefits. In contrast, the evidence on job performance consistently indicates a positive relationship. While previous research on lifelong learning and the labor market starts with the premise that lifelong learning has a positive effect and tends to focus on factors influencing participation, this study contributes by synthesizing the evidence into five clusters, offering a clear overview of how lifelong learning impacts the labor market.

Keywords: *lifelong learning, older workers, labor market outcomes, employability, population aging*

JEL classification: *I26, J14, J24*

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1. Introduction

Population aging is a widespread phenomenon driven by increasing life expectancy and declining fertility. This demographic trend is especially evident in developed societies, including European countries, where labor force is steadily aging. In Europe, the average age of workers aged 20 and over falls within the 40-45 age range, with Eastern and Southern EU countries generally experiencing the most rapid increases in the mean age of the labor force (Pinkus & Ruer, 2025). Based on the European Union (EU) Labour Force Survey (Eurostat, 2024), the European Centre for the Development of Vocational Training (Cedefop, 2025b) calculated that between 2013 and 2023, the share of workers aged 50-64 increased from 27.4% to 31.8%, while the share of workers aged 65 and older rose from 2.0% to 3.08% in the EU.

In today's world, with rapidly changing technology, lifelong learning – particularly for older workers – is considered essential (Baltic Sea Labour Forum for Sustainable Working Life, 2022; Bingham, 2019; Tikkanen & Nyhan, 2006; Walwei & Deller, 2021). As a key indicator of lifelong learning, Cedefop (2025a) calculated, using EU Labor Force Survey data (Eurostat, 2024), that participation in learning among the employed population in the EU aged 50-64 increased from 8.0% to 11.0% between 2013 and 2023.

Lifelong learning is "all learning activity undertaken throughout life, with the aim of improving knowledge, skills and competences within a personal, civic, social and/or employment-related perspective" (Commission of the European Communities, 2001, p. 9). It includes formal, non-formal, and informal modalities (UNESCO Institute for Lifelong Learning, 2022). Its overarching aim is to improve the workers' positions in the labor market. However, when reviewing literature on lifelong learning and the labor market in the context of population aging, many studies begin with the assumption that lifelong learning is inherently beneficial for older people and therefore examine it primarily as a dependent variable. This approach leaves a gap in research on the actual usefulness of lifelong learning. This study addresses that gap by examining how lifelong learning influences labor market outcomes of older workers and by investigating the actual labor market outcomes of lifelong learning for this group. Thus, the guiding research question is: how does lifelong learning influence labor market outcomes in the context of population aging? The research focuses on the EU. When investigating older workers, it is important to note that there is no universally accepted definition of this group (Hardy, 2006; Pitt-Catsouphes & Smyer, 2006). The definition depends on the contextual factors such as retirement rules, age-discrimination protections, public perceptions of aging, subjective feelings of being old, and life expectancy. Some studies consider older workers as those aged 50 or 55 and above, while others use a lower threshold, such as 40 and above.

2. Methodology

The methodology used in this research is a systematic literature review. The review followed the PRISMA 2020 guidelines (Page et al., 2021a; Page et al., 2021b), which explain the process of literature exclusion and inclusion.

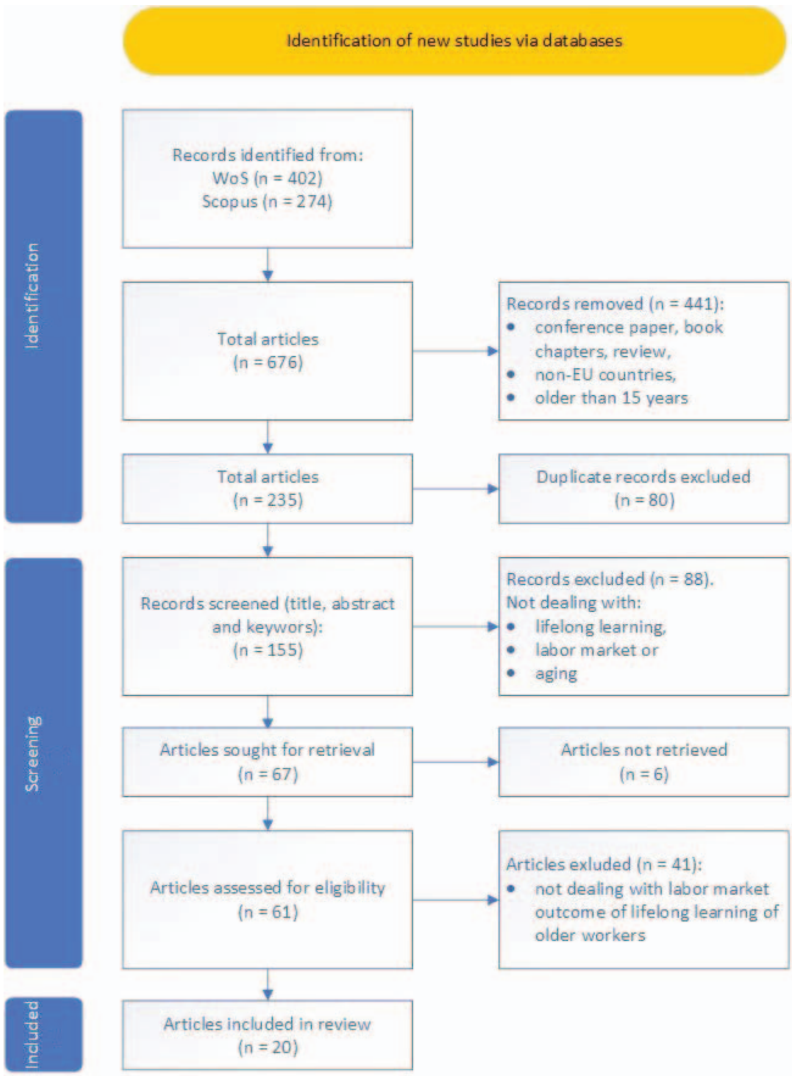
The first step involved the selection of databases. Two major databases widely used in business and economics research were chosen: Web of Science Core Collection and Scopus. To identify studies related to the research question, three groups of keywords were used.

- Keywords for *lifelong learning*: *life-long learning* OR *lifelong learning* OR *lifelong training* OR *life-long training* OR *lifelong education* OR *life-long education* OR *continuous education* OR *continuous learning*;
- Keywords for *labor market*: *employability* OR *labour market* OR *labor market* OR *job market* OR *workforce* OR *labourforce* OR *laborforce* OR *labour force* OR *labor force* OR *employer* OR *worker* OR *employee* OR *manpower*;
- Keywords for *population aging*: *ageing* OR *aging* OR *older* OR *elderly*.

These were combined into complete Boolean search strings. For WoS: *life-long learning* OR *lifelong learning* OR *lifelong training* OR *life-long training* OR *lifelong education* OR *life-long education* OR *continuous education* OR *continuous learning* (Topic) and *employability* OR *labour market* OR *labor market* OR *job market* OR *workforce* OR *labourforce* OR *laborforce* OR *labour force* OR *labor force* OR *employer* OR *worker* OR *employee* OR *manpower* (Topic) and *ageing* OR *aging* OR *older* OR *elderly* (Topic). For Scopus, the complete search string was TITLE-ABS-KEY (*life-long learning* OR *lifelong learning* OR *lifelong training* OR *life-long training* OR *lifelong education* OR *life-long education* OR *continuous education* OR *continuous learning*) AND TITLE-ABS-KEY (*employability* OR *labour market* OR *labor market* OR *job market* OR *workforce* OR *labourforce* OR *laborforce* OR *labour force* OR *labor force* OR *employer* OR *worker* OR *employee* OR *manpower*) AND TITLE-ABS-KEY (*ageing* OR *aging* OR *older* OR *elderly*).

The search took place on October 24, 2024 and yielded 402 articles in WoS and 274 in Scopus, resulting in 676 articles. Inclusion criteria were applied to include relevance: studies had to focus on EU countries (the UK was included initially and could be excluded later), be published articles only, and fall within the period 2010-2024 to capture contemporary research while maintaining a sufficiently broad evidence base. The language of the publications was not restricted to maintain a broader base. After filtering by country/region and publication type, 441 studies that did not meet the inclusion criteria were excluded. Of the remaining 235 articles, 80 duplicates were removed. The titles, abstracts, and keywords of the remaining 155 articles were screened, leading to the exclusion of 88 additional studies. Of the 67 articles that remained, six could not be retrieved. The final set consisted of 61 articles, including five non-English publications: three in Spanish, one in Dutch, and one in Polish. These were translated into English using Sider AI PDF translator. Ultimately, 20 articles met all eligibility criteria and were included in this systematic literature review. Three of these were translated: Corrales-Herrero and Rodríguez-Prado (2016), originally written in Spanish, Gigol and Pajewska-Kwaśny (2022), originally written in Polish and Van Vuuren et al. (2011), originally written in Dutch. The selection process is illustrated in the PRISMA flow diagram (Figure 1).

Figure 1: PRISMA flow diagram of selection and screening process



Source: Author's illustration, adapted from Page et al. (2021a) and Page et al. (2021b)

2.1. Methodological approaches in the literature

When assessing the eligibility of papers, the focus was on studies that used a labor market outcome (e.g. employability) as a dependent variable and examined lifelong learning as a factor influencing those outcomes. However, most studies treated lifelong learning as a dependent variable; these were excluded from this review. Additionally, many studies simply stated that lifelong learning is beneficial and necessary in the labor market, without examining its actual outcomes; these were also excluded. Only studies that addressed the impact of lifelong learning on older workers' labor market outcomes were included, although this relationship was not always the primary focus of the study. The included studies employed a range of methodological approaches, predominantly quantitative designs, such as regression multilevel models.

The studies drew on various data sources. Some included national and regional labor force surveys that provided comparable cross-national data. Others relied on longitudinal data such as the Survey of Health, Ageing and Retirement in Europe – SHARE (Börsch-Supan et al., 2013), which offered insights into the impact of lifelong learning on labor market outcomes over time. Several studies also used case-specific data, which provided perspectives at the organizational or individual level within specific industries. Although the review focused on EU countries, several studies examined a broader context and additionally included non-EU countries, such as Switzerland.

A methodological quality assessment was conducted for all included studies. Although most studies were quantitative, there were two studies with a mixed quantitative and qualitative approach and one qualitative study. Mixed-methods studies were evaluated separately for their quantitative and qualitative components. The methodological quality of quantitative studies was assessed using a modified version of the Newcastle-Ottawa Scale (NOS) (Wells et al., 2000). The adaptation was partially informed by previous applications and discussions of the NOS in the literature (Gualdi-Russo & Zaccagni, 2026). The assessment covered the domains of sample selection (including appropriateness, size, and exposure assessment), comparability, and outcome assessment (including measurement quality and statistical analysis). Each criterion was scored from 0 to 2 points according to predefined thresholds. The final instrument had a maximum score of 12 points. The quality of studies was classified as high (9-12 points), moderate (6-8 points), or low (0-5 points) based on proportional thresholds. Given the small number of qualitative studies, a simplified set of criteria was applied, focusing on data analysis and credibility or validity, each scored from 0 to 2 points (maximum 4 points). To ensure comparability with quantitative studies, scores were interpreted proportionally, with high quality defined as 3-4 points, moderate quality as 2 points, and low quality as 0-1 point.

A detailed description of the criteria and scoring procedures is provided in Appendix A, with results presented in Table A1 for quantitative studies and Table A2 for qualitative studies. Most studies were assessed as high quality, with a smaller number rated as moderate. The studies were clustered using an inductive, data-driven approach that did not rely on predefined themes. Instead, clusters were developed through iterative examination of the articles. This bottom-up process examines similarities in research and allows patterns and relationships to emerge from the included studies (Clarke & Braun, 2017; Popay et al., 2006).

A summary of included studies with their key characteristics is presented in Table 1.

Table 1: Summary of included studies

Author (year)	Country	Sample	Methodology	Main findings
Corrales-Herrero and Rodríguez-Prado (2016)	Spain	Data from Survey on Adult Participation in Learning Activities, 12905 participants selected	Propensity score matching, logistic regression	The impact of formal learning on employability is not significant for any age group. The effect of informal learning for the oldest groups is unclear; some models show a significant positive relationship, while others show no significant effect.
Dellve et al. (2025)	Sweden	Older assistance nurses, nurses, teachers, (female dominated public sector), 1342 participants	CFA, SEM	Participation in organizational learning programs positively influences the attractiveness of work, autonomy, and relatedness for older workers.
Gigol and Pajewska-Kwaśny (2022)	Poland	Survey of 157 employees of Dean's office of various universities in Poland.	EFA, Kolmogorov–Smirnov test, Student's t-test for independent samples, moderated mediation modeling. Boostraping to prevent significance bias.	Lifelong learning positively influences satisfaction with salary and job satisfaction, not only for younger but also for older employees.
Goštautaitė and Šerelytė (2024)	Lithuania, Latvia, and Estonia	Survey of an organization in financial sector, 2256 participants	Moderation regression models	The relationship between age and perceived employability is negative, but lifelong learner characteristics mitigate this negative relationship.
Hällsten (2012)	Sweden	Longitudinal data based on various annual population registers	Matching techniques are combined with individual-level fixed effects panel data methods	Lifelong learning at the tertiary level later in life positively affects employment, with a stronger impact for females and those with vocational education. Earnings increase slightly, particularly for females.
Hennekam (2015)	Netheralands	920 surveys and 11 semi-structured in-depth interviews. Subjects are working people registered at a job agency specialized for older employees.	Mixed methods: regression and content analysis	Continuous learning ability is positively related to salary. It also positively influences career satisfaction for older workers have a desire to develop themselves. Those who do not wish to continuously learn want to be valued as they already are and may feel pushed toward retirement.
Hüber et al. (2022)	Germany	Older working people, 633 participants, longitudinal data	Chi2-tests, independent samples t-tests, paired sample t-tests and mixed-design ANOVAs with repeated-measures factor time and between-subjects factor group, Cohen's d,	Multicomponent training as a form of lifelong learning leads to changes such as improved coping with work-related stress. It also increases the self-assessment of professional competence and self-efficacy.

Author (year)	Country	Sample	Methodology	Main findings
Korsakienė et al. (2017)	Lithuania	Older employees working in science, education and public organizations, 107 participants	EFA, correlation, regression	There is a positive correlation between the desire for learning and development and work engagement among older workers.
Lunau et al. (2015)	16 European countries	Data from Survey of Health, Aging and Retirement in Europe (SHARE) and English Longitudinal Study of Ageing	Regression, multilevel models	The association between lifelong learning and work stress is significantly negative. Lifelong learning significantly reduces work stress for workers with lower education. However, for those with higher education, the reduction is not significant.
Mäcken et al. (2022)	15 European countries	Data from longitudinal Survey of Health, Aging and Retirement in Europe (SHARE)	Discrete-time event-history analyses, two-step meta-analytic approach	Higher participation of older workers in lifelong learning is associated with a decrease in the social gradient in involuntary exit from employment, but the effect size is small.
Siivonen and Isopahkala-Bouret (2016)	Finland	Interviews with 24 adult graduates (upper secondary and university)	Analysis from a discursive-narrative point of view	Some graduates see ageing as an advantage, while others see it as a disadvantage. Advantages include a willingness to invest in development and continuous education, combined with work experience and current qualifications, which gives an edge in employability. This holds special meaning for both graduates and employers who value these qualities. Disadvantages include it being too late to prove employability, find employment, and benefit from it in their working lives, which can become a major disappointment.
Turek and Perek-Bialas (2013)	Poland	Data from the representative Activating Senior Potential in Ageing Europe (ASPA) survey (2009) of 1037 employers who were interviewed by telephone (CATI)	Regression	Companies implementing training plans assessed the productivity of older workers as higher than companies that did not use those policies.
Urbaniak and Wiktorowicz (2014)	Poland	Survey of 3200 older people (CAPI) and 1011 employers (CATI) and quality researchers including and a panel of experts.	Descriptive statistics, chi-square test and factor analysis; in-depth interviews, casual interviews	The most important factor for equal opportunities in the labor market for older workers is related to upskilling.

Author (year)	Country	Sample	Methodology	Main findings
Valente et al. (2023)	Spain	Survey of 1692 former students who had graduated from the Open University of Catalonia (Quota sampling); Data from the National Employment Survey	CFA, regression	Earning gains from obtaining a degree are higher for younger graduates than for older graduates. In the oldest groups, earning gains become insignificant or even negative.
Van der Heijden et al. (2015)	Netherlands	Survey of 182 primary school teachers from 9 schools	Hierarchical regression, CFA	Developmental opportunities are positively related to employability and work engagement. The positive effect on employability is stronger for older employees than for younger employees.
Van der Klink et al. (2014)	Netherlands	Survey among academic staff at the Open University, 139 responses	Hierarchical regression, one-way ANOVA	Age is related to informal learning elements, but not directly to employability. It is possible that informal learning mediates the relationship between age and employability, but this is not discussed in the research.
Van Vuuren et al. (2011)	Netherlands	Survey among employees of nine elementary school, 178 responses	MANOVA, moderation analysis	Older workers have lower employability than younger workers, but those who participate in lifelong learning have higher employability.
Węgrzyn and Salamaga (2023)	EU-27	Data from the Community Innovation Surveys (CIS), Labor Force Survey and data on job-to-job rotation.	Panel error correction models (ECM), panel causality tests	An increase in the population participating in lifelong learning may increase or decrease transitions from inactivity to employment, or from employment to inactivity or unemployment, depending on the level of innovation in the economy.
Wilckens et al. (2023)	Germany	Multilevel data of 556 older employees and 661 managers from 101 organizations.	linear mixed-effect models	Development practices moderate the influence of health on retirement intentions. A higher level of individual development is particularly associated with a higher preferred retirement age for employees in good health.
Žnidaršič et al. (2021)	Slovenia	Survey in 3 companies, 259 responses	independent t-test; regression	After learning, older workers are better able to adapt to the changing work environment than younger workers.

Source: Author's compilation

The results of the reviewed studies were grouped into thematic clusters related to specific labor market outcomes identified in those studies: employability, exit from employment, earnings, job satisfaction, and job performance.

Due to labor market outcomes often being interrelated, some studies addressed more than one outcome. These studies were therefore assigned to all relevant clusters to ensure a comprehensive analysis and to enable a detailed synthesis of the thematic clusters.

3. Results

This section provides a further analysis of the thematic clusters identified in this systematic literature review: employability, exit from employment, earnings, job satisfaction, and job performance.

3.1. Employability

Employability was the most frequently examined outcome, which is not surprising given its central role in the literature search. Across the reviewed studies, the results regarding the relationship between lifelong learning and the employability of aging workers are mixed, with evidence of positive, negative, and non-significant effects.

Węgrzyn and Salamaga (2023) distinguish between long-term and short-term effects of increasing participation in lifelong learning in countries with different levels of innovation (innovation leaders, strong innovators, moderate innovators and emerging innovators). In innovation leader countries, a higher share of the population participating in lifelong learning significantly reduces transitions from inactivity to employment long-term. In moderate-innovator countries, however, the long-term effect was the opposite, significantly increasing the transition from inactivity to employment. In innovation leader countries, the short-term effect is a significant reduction in the transition from inactivity to employment. In all other cases, transitions from inactivity or unemployment to employment were not significant.

Siivonen and Isopahkala-Bouret (2016) examined how adult graduates negotiate and interpret aging within the context of employability discourse. The researchers also explored the consequences of pursuing formal, academically-oriented education in adulthood rather than in youth. Some graduates viewed aging as an advantage, arguing that a willingness to invest in their own development and continuous education at any age strengthened their employability, due to the combination of extensive work experience and current qualifications. Others perceived aging as a disadvantage, noting that completing a degree later in life left to little time to demonstrate employability to potential employers and secure employment.

Hällsten (2012) examined economic returns to tertiary degrees earned later in life. The findings show that lifelong learning at the tertiary level has a major positive effect on employment. This effect varies by gender and birth cohorts: employment increases across all cohorts, except for men with academic education in the youngest birth cohort. In general, the effect is stronger for women and for individuals with vocational education, with the largest gains observed among women with vocational schooling.

Corrales-Herrero and Rodríguez-Prado (2016) analyzed the impact of formal and informal lifelong learning on employability. Among unemployed individuals of all ages, informal learning had a positive impact on employability, whereas formal learning showed inconsistent and non-significant results across all age groups. Although the results were not significant, they were negative, suggesting that unemployed individuals who participated in formal lifelong learning were less likely to be employed than those who did not participate in lifelong learning. When age was taken into account, the results for formal learning remained consistent with the overall findings and were not significant for any group. The effects of participation in informal learning were strongest among the youngest unemployed and decreased with age. For older unemployed individuals, who were the focus of this systematic literature review, participation in informal learning produced mixed outcomes: some models indicated significant positive effects on employment, while others showed no significant results.

Urbaniak and Wiktorowicz (2014) investigated factors contributing to equal opportunities in the labor market for older workers. The analysis showed that upskilling measures targeted at older workers were the most important factor for improving the equality of opportunities. Both older workers and employers identified identical tools as essential for achieving equal opportunities in the labor market. Additionally, one in ten employers considered improving the skills of older workers an important measure for increasing their employment.

Several studies examined interactions between lifelong learning and age. Van der Heijden et al. (2015) found that developmental opportunities are positively related to employability. There was a significant interaction effect between age and developmental opportunities on employability. The positive effects of developmental opportunities were stronger for older employees than for younger ones.

Goštautaitė and Šerelytė (2024) studied the perceived automation risk and the characteristics of lifelong learners as factors that may influence the negative relationship between age and employability. A significant negative relationship was found between age and perceived employability. The strongest predictor of perceived employability in the model was lifelong-learner characteristics, which were strongly positively associated with employability. The interaction between age and lifelong-learner characteristics was also significantly associated with perceived employability. The negative relationship between age and perceived employability was stronger when lifelong-learner characteristics were lower, but when they were higher, the relationship was not significant. These results suggest that lifelong-learner characteristics buffer the negative relationship between age and perceived employability.

Van der Klink et al. (2014) investigated the contribution of formal and informal learning to employability. Age was a significant predictor for informal learning: it was negatively associated with networking both within and outside one's own organization. Although age was not significant in the employability models, networking within one's own organization had a significant positive impact on corporate sense, while networking outside one's own organization had a significant positive impact on anticipation, optimization, and personal flexibility. While not explicitly addressed in the study, these findings suggest that informal learning may mediate the relationship between age and employability.

Van Vuuren et al. (2011) examined how age influences the relationship between lifelong learning and sustainable employability. Sustainable employability consists of three elements: vitality, work ability, and employability (Sociaal-Economische Raad, 2009). The study found a statistically significant multivariate main effect for age and a significant univariate main effect for employability, but not for work ability or vitality. Aging is associated with a decrease in employability, but not with a decrease in work ability or vitality. Lifelong learning also showed a significant multivariate main effect. Univariate tests indicated that higher levels of lifelong learning are associated with significantly higher employability, work ability, and vitality compared to lower levels. Employees with more interest in and opportunities for lifelong learning are more employable, more able to work, and more vital than those with less interest and fewer opportunities. The interaction between age and lifelong learning on sustainable employability was also significant. Older workers have lower employability than younger workers, but those who participate in lifelong learning have higher employability. Older workers with limited interest in and opportunities for lifelong learning have lower employability than older workers with high interest and more opportunities. The differences in employability between age groups are smaller for those who participate in lifelong learning. Older employees with below-average participation in lifelong learning have low work ability, while older employees with above-average participation have high work ability.

To summarize this cluster, there is no clear answer as to whether lifelong learning improves the employability of older workers. However, it often buffers the negative effects of aging. Informal lifelong learning leads to better outcomes than formal learning. Longitudinal data on the sustainability of employability improvements through lifelong learning are scarce.

3.2. Exit from employment

In the study by Węgrzyn and Salamaga (2023), increases in the share of population participating in lifelong learning produced different long-term effects depending on countries' innovation levels. In innovation leader countries, the transition from employment to inactivity or unemployment is significantly reduced. In strong-innovator countries, the effect is reversed: increased lifelong learning leads to an increased transition from employment to inactivity or unemployment. In moderate-innovator countries, the transition from employment to inactivity increases significantly, while the transition from employment to unemployment decreases. The short-term effect of increased lifelong learning impacts only a small number of transition types. In innovation leader countries, the transition from employment to inactivity is significantly reduced, while in highly innovative and emerging countries, it significantly increases the transition from employment to unemployment. Other combinations of effect duration and innovation categorization did not result in a significant transition from employment to inactivity or unemployment.

Mäcken et al. (2022) examined country-specific differences in the relationship between education and voluntary or involuntary exit from the labor market, as well as whether these differences can be attributed to institutional characteristics of the countries. The results showed that there is a social gradient in exiting working life in most countries. Higher participation of older workers in lifelong learning was associated with a reduction in the social gradient in involuntary exit from employment, although the effect size was small.

Several studies in this cluster included moderation modeling. Wilckens et al. (2023) examined the role of human resource practices in relation to older workers' health and retirement intentions, including their preferred retirement age and their intention to work after reaching retirement age. Individual development practices were not significantly related to retirement intentions or later-life employment. However, when examining the moderation of individual development practices on the influence of health on retirement intentions, there was a significant interaction effect between health and individual development practices on employees' preferred retirement age, but not on their employment intentions in later life. Employees in good health who experienced higher levels of development practices preferred a later retirement age.

Hennekam (2015) researched the influence of social skills competence and continuous learning ability on career success and career satisfaction among older workers. The correlation between continuous learning ability and career satisfaction is somewhat contradictory. Some respondents valued their growth and self-development, which made them feel like valuable members of the organization and influenced their attitudes toward retirement and their willingness to remain employed. However, others indicated that they were satisfied with their current status and wanted to be valued as they already are. They felt that expectations for further development could pressure them to leave the workforce. Since the section of the article addressing exit from employment is related to career satisfaction, the survey results concerning employee satisfaction are also discussed in the job satisfaction cluster.

Dellve et al. (2025) investigated whether participation in employer-provided skills and learning programs strengthens older employees' abilities to perform their work meaningfully, thereby increasing job attractiveness and willingness to remain in their current positions. The relationship between active participation in organizational learning programs and retirement preference was not significant. As in Hennekam (2015), exit from employment is linked to job satisfaction. This part will therefore also be discussed in the job satisfaction cluster.

To sum up, as in the employability cluster, findings on the influence of lifelong learning on exit from employment are contradictory. However, the correlation is more often positive than negative or insignificant. In several studies, exit from employment is associated with job satisfaction. For this reason, these analyses are also included in the job satisfaction cluster. It is important to note that countries have different policies regarding the statutory retirement age and different rules for early retirement and working after retirement age.

3.3. Earnings

In Hennekam's (2015) study on the influence of social skills competence and continuous learning ability on career success, salary level was used as a measure of career success. Continuous learning ability was positively associated with salary (career success).

In addition to examining the effect of lifelong learning at the tertiary level on employability, Hällsten (2012) also investigated its impact on earnings. The results showed a weak increase in earnings. The opportunity costs of studying are foregone earnings, and individuals with low prior earnings have lower opportunity costs, making them more likely to enroll in tertiary education. As with employability, the increase in earnings was stronger for females than for males. Females with vocational upper-secondary schooling experienced the same increase in earnings while employed.

Valente et al. (2023) explored earning gains from obtaining a university degree, focusing on students at a virtual university who tend to be older. Overall, both undergraduate and graduate males experienced greater earning gains compared to females. However, when age was taken into account, earning gains were higher for younger graduates than for older ones. Among younger age groups, males experienced greater earning gains than females, while in older age groups, females experienced greater gains than males. In the oldest groups, earning gains became insignificant or even negative. Male graduates aged 50-54 showed no significant earning benefits, and in the 60-64 age group, the gain was negative, but not significant. Female graduates still experienced earning benefits in the 50-54 age group, but in the 60-64 age group, they faced a significant negative gain.

Gigol and Pajewska-Kwaśny (2022) examined the influence of lifelong learning on job satisfaction, including satisfaction with salary in their modeling. For this reason, the study is included in both the earnings cluster and the job satisfaction cluster. Additionally, salary was a mediator in the relationship between lifelong learning and job satisfaction. The results show that lifelong learning had a positive effect on satisfaction with salary. Age was not a statistically significant mediator in this relationship: the positive influence of lifelong learning on satisfaction with salary was significant for both younger and older employees.

In summary, the findings indicate that the effect of lifelong learning on earnings is not straightforward. Lifelong learning generally has a positive effect on earnings, but for older workers, some studies show a positive effect, while others indicate that the effect diminishes with age or may even become negative.

3.4. Job satisfaction

As mentioned in the exit from employment cluster, Hennekam (2015) examined the influence of continuous learning ability on career satisfaction. The results are contradictory. On the one hand, older workers who engage in continuous development are generally more satisfied with their careers, indicating a positive influence on career satisfaction. On the other hand, the need to constantly stay updated with new developments can sometimes feel like a threat, thus having a negative influence on career satisfaction. Overall, continuous learning ability positively influences career satisfaction when older workers have a genuine desire for self-development.

Dellve et al. (2025) investigated the relationship between employer-provided learning programs and various work-related outcomes. The influence of organizational learning programs is found to positively affect the attractiveness of work for older employees.

Lunau et al. (2015) explored the association between education and work stress among older workers in 16 European countries. They found that in each country, workers with lower educational levels experienced higher levels of work stress. When labor market policies were taken into account, lifelong learning was included in the model as one of the policy measures. A significant negative association between lifelong learning and work stress was found. Additionally, when policy measures were interacted with educational level, lifelong learning significantly reduced work stress for workers with lower education, but the decrease in work stress for those with higher education was not significant.

Hüber et al. (2022) investigated how lifelong learning can support older workers. Multi-component training focused on competence expectations, stress management, and cognitive, metacognitive, and psychomotor training was conducted. The assessed outcomes of the training were changes in subjective health, self-efficacy, self-concept of professional competence, stress management, and cognitive abilities. For the purposes of this systematic literature review, it should be noted that the elements of coping with stress are strongly related to work (e.g. professional ambition, willingness to work to exhaustion), so they can be considered as work stress and are therefore included in this cluster.

Siivonen and Isopahkala-Bouret (2016), who examined adult graduates' perceptions of employability, also reported both positive and negative experiences relate to job satisfaction. Some participants felt that earning a degree in adulthood has a special meaning and is valued by employers who respect adult education and degrees earned later in life. Others, however, felt disappointed because they perceived it as too late in their careers to benefit from the qualification, which negatively affected their job satisfaction.

The research conducted by Gigol and Pajewska-Kwaśny (2022) is also included in this cluster. Their study found a statistically significant positive relationship between lifelong learning and job satisfaction, indicating that lifelong learning opportunities increase job satisfaction. As in the earnings cluster, age did not moderate this relationship: the positive effect of lifelong learning on job satisfaction was significant for both younger and older employees.

When summarizing the job satisfaction cluster, at first glance, the results appear more straightforward than in previous clusters. In general, lifelong learning positively affects job satisfaction among older workers, although the increase is not always statistically significant. However, there are instances where negative effects are present, particularly when workers do not wish to pursue lifelong learning and feel pressured, or when they believe it is too late in their careers to benefit from it.

3.5. Job performance

Žnidaršič et al. (2021) compared older and younger workers in terms of their motivation to learn and the outcomes of learning. The research did not find significant differences in intrinsic learning motivation between older and younger workers, but there was a significant difference in extrinsic learning motivation. Older workers are less likely than younger workers to participate in learning to achieve career goals and more likely to do so to improve work efficiency and promote knowledge transfer. The results also show that after learning, older workers adapt better to the changing work environments than younger workers.

Turek and Perek-Bialas (2013) examine how employers perceive the productivity of older workers compared to younger ones. Employers generally rate older workers lower in productivity and hard skills, but higher in soft skills compared to younger workers. However, when measures to increase the productivity of older workers, including training plans, were included in the modeling, companies implementing these policies assessed productivity higher than companies that did not use such policies.

Van der Heijden et al. (2015) also investigated the relationship between developmental opportunities and work engagement. They found the relationship to be positive. It was not influenced by age, so the relationship was positive for both older and younger workers.

Dellve et al. (2025) further examined how participation in employer-provided learning programs influences autonomy, competence, and relatedness among older workers. All these relationships were found to be positive.

Korsakienė et al. (2017) analyzed employee-related and work-related factors affecting the work engagement of older workers. There was a positive correlation between the desire for learning and development and work engagement.

The study conducted by Hüber et al. (2022) also contributed to this cluster. Their training program for older workers resulted in increased self-assessment of professional competence and self-efficacy.

The job performance cluster provides the most consistent findings in the entire review. Across all studies, the relationship between lifelong learning and job performance of older workers is positive, with no evidence of negative effects.

4. Conclusion

There is a substantial body of literature on lifelong learning, but most studies examine it as an outcome, rather than as a factor influencing labor market outcomes for older workers. This systematic literature review analyzed 20 studies focusing on the effects of lifelong learning on the labor market. The outcomes are grouped into five clusters: employability, exit from employment, earnings, job satisfaction, and job performance.

Across all clusters except job performance, the direction of the relationship between lifelong learning and labor market outcomes is not straightforward. It is not clear whether lifelong learning increases the employability of older workers, although it frequently buffers the negative effects of aging. Informal learning tends to yield better results than formal learning. Results in the exit from employment cluster are also mixed, though the relationship tends to be more positive than negative. When investigating exit from employment, it is important to consider differences in statutory retirement ages and policies regarding (early) retirement and working after retirement age. In the earnings cluster, lifelong learning generally has a positive effect, but some studies reveal that this effect diminishes with age or can even become negative. Although lifelong learning initially appears to have a positive effect on job satisfaction for older workers, this effect is not always significant. Negative effects occur when workers feel pressured to pursue lifelong learning, or when they are disappointed because they perceive that it is too late in their careers to benefit from it. In contrast to the other clusters, the job performance cluster shows a positive relationship between lifelong learning and job performance. During the analysis, strong connections emerged between the exit from employment and job satisfaction clusters, as well as between the job satisfaction and job performance clusters.

The studies included in this review were conducted in diverse contexts and used different measures of lifelong learning and labor market outcomes. Some variability in results can therefore be attributed to methodological and contextual differences. However, this does not fully explain the inconsistencies. Even under similar conditions, outcomes differ, which is most clearly illustrated in qualitative studies including in-depth interviews with individuals who participated in lifelong learning. Additionally, differences in older workers' willingness to participate in lifelong learning also contribute to divergent outcomes. Furthermore, the relatively small number of longitudinal studies may contribute to mixed findings, highlighting the need for further longitudinal research.

Overall, this review provides insights into the effects that older workers can expect from lifelong learning and clarifies that these effects do not always align with the common claim that lifelong learning *solves problems* for older workers. Nevertheless, across all clusters, positive outcomes occur more often than negative ones, even if the patterns are not uniform.

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Utjecaj cjeloživotnog učenja na ishode na tržištu rada u uvjetima starenja stanovništva: sustavni pregled literature

Ana Štambuk[1]

Sažetak

Poboljšanje položaja starijih radnika na tržištu rada često se povezuje s važnošću cjeloživotnog učenja. Cilj je ovog istraživanja ispitati ishode cjeloživotnog učenja za starije radnike na tržištu rada putem sustavnog pregleda literature koji obuhvaća članke temeljene na zemljama Europske unije, objavljene između 2010. i 2024. godine, a indeksirane u bazama WoS i Scopus. Utjecaj cjeloživotnog učenja na ishode na tržištu rada podijeljen je u pet kategorija: zapošljivost, izlazak iz zaposlenja, zarada, zadovoljstvo poslom i radna uspješnost. U svim kategorijama osim radne uspješnosti, smjer odnosa između cjeloživotnog učenja i ishoda na tržištu rada nije jednoznačan. Kada je riječ o zapošljivosti, cjeloživotno učenje ne povećava je uvijek, ali često ublažava negativne učinke starenja. Rezultati vezani uz izlazak iz zaposlenja ishodi također su nejasni, iako odnos češće pokazuje pozitivan nego negativan smjer. Što se tiče zarade, cjeloživotno učenje pokazuje pozitivan učinak, no taj učinak može slabiti s dobi ili čak postati negativan. Čini se da cjeloživotno učenje pozitivno utječe na zadovoljstvo poslom, ali učinak nije uvijek statistički značajan, a mogu se javiti i negativni učinci, primjerice kada se radnici koji ne žele sudjelovati u cjeloživotnom učenju osjećaju ugroženo ili kada smatraju da je prekasno da bi od toga imali stvarne koristi. Suprotno tome, kategorija radne uspješnosti dosljedno ukazuje na pozitivan odnos između cjeloživotnog učenja i radne uspješnosti. Dok se prethodna istraživanja o cjeloživotnom učenju i tržištu rada često temelje na pretpostavci da cjeloživotno učenje ima pozitivan učinak te se uglavnom usredotočuju na čimbenike koji utječu na sudjelovanje, ovo istraživanje doprinosi sintetiziranjem dokaza u pet kategorija, pružajući jasan pregled načina na koji cjeloživotno učenje utječe na tržište rada.

***Ključne riječi**: cjeloživotno učenje, stariji radnici, ishodi na tržištu rada, zapošljivost, starenje stanovništva*

***JEL klasifikacija**: I26, J14, J24*

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Appendix

Quality assessment framework for quantitative studies

Sample selection (sample appropriateness and representativeness, sample size, exposure assessment)

Sample appropriateness and representativeness

2 points: The sampling strategy is appropriate and well-justified for the research objective, providing a sample that is either broadly representative of the target population or highly relevant and well-defined for the specific study context (e.g. institutional datasets or specialized populations).

1 point: The sampling strategy is described and partially justified, but the sample is limited in scope or representativeness.

0 points: The sampling method is not described or is clearly inappropriate for the research objective.

Sample size

2 points: Sample size meets the recommended criteria for statistical analysis (i.e., ≥ 100 observations and ≥ 10 observations per predictor variable), or is otherwise justified through a reported power analysis.

1 point: Sample size is acceptable but below ideal thresholds (i.e. it meets only one of the following: ≥ 100 observations or ≥ 8 observations per predictor variable).

0 points: Sample size is insufficient (< 8 observations per predictor variable) and no justification is provided.

Exposure assessment

Exposure to lifelong learning (participation, willingness to participate, etc.)

2 points: Exposure variables are measured using validated or well-established instruments, objective data (e.g. administrative records), or verifiable self-report (i.e. data that can be confirmed from external sources, whether or not it was checked, e.g. participation in a lifelong learning program in the last 12 months), or measures that are clearly defined and widely used in the literature.

1 point: Exposure variables are based on non-validated measures, including non-verifiable self-report, but are clearly described in sufficient detail to allow replication.

0 points: Exposure variables are poorly described and lack sufficient detail.

Comparability (control of confounding factors)

2 points: The study applies multivariate statistical analysis, controlling for three or more relevant confounding variables, or uses advanced analytical methods (e.g. multiple regression, fixed-effects models, matching techniques, or structural equation modeling.

1 point: The study includes statistical control for one or two confounding variables.

0 points: No control for confounding factors is applied (e.g. descriptive analysis or bivariate analysis only).

Outcome (assessment of outcome, statistical analysis quality)

Assessment of outcome: labor market outcome

Outcome measurement is assessed using the same criteria as exposure measurement, with emphasis on the validity, clarity, and replicability of the measures.

Statistical analysis quality

2 points: Statistical analysis meets all three of the following criteria: 1) appropriate methods are used for the research question and data; 2) the analysis is described in sufficient detail to allow replication; 3) effect sizes or measures of association are reported (e.g. coefficients, odds ratios)1 point: Two of the above criteria are met.

0 points: One or none of the criteria are met.

Quality assessment framework for qualitative studies

Data analysis

2 points: The analytical approach is clearly described and systematically applied (e.g. discursive, narrative).

1 point: The analytical approach is mentioned but only briefly described, with limited detail on how the analysis was conducted.

0 points: The analysis is unclear, poorly described, or not explained.

Credibility / validity

2 points: The study addresses credibility using recognized qualitative techniques (e.g. transparent interpretation process, use of quotations, reflexivity, or consistency in analysis).

1 point: Some consideration of credibility is present, but limited or implicit.

0 points: No discussion of credibility or validity is provided.

Table A1: Quality assessment of quantitative studies

Author (year)	Sample selection			Comparability	Outcome		Total	Quality
	Sample appropriateness and representativeness (0-2)	Sample size (0-2)	Exposure elements (0-2)	Control of cofounding factors (0-2)	Assessment of outcome (0-2)	Statistical analysis (0-2)	(0-12)	
Corrales-Herrero & Rodríguez-Prado (2016)	2	2	2	2	2	2	12	High
Dellve et al. (2025)	1	2	2	2	1	2	10	High
Gigol & Pajewska-Kwaśny (2022)	1	2	1	2	2	2	10	High
Goštautaitė & Šerelytė (2024)	1	2	2	2	2	2	11	High
Hällsten (2012)	2	2	2	2	2	2	12	High
Hennekam (2015)	2	2	2	2	2	2	12	High
Hüber et al. (2022)	2	2	2	1	2	2	11	High
Korsakienė et al. (2017)	1	2	1	0	2	2	8	Moderate
Lunau et al. (2015)	2	2	2	2	1	2	11	High
Mäcken et al. (2022)	2	2	2	2	2	2	12	High
Turek & Perek-Bialas (2013)	2	2	2	2	1	2	11	High
Urbaniak & Wiktorowicz (2014)	2	2	2	0	1	2	9	High
Valente et al. (2023)	2	2	2	2	2	2	12	High
Van der Heijden et al. (2015)	1	2	2	2	2	2	11	High
Van der Klink et al. (2014)	2	2	2	2	2	2	12	High
Van Vuuren et al. (2011)	1	2	2	1	2	2	10	High
Węgrzyn & Salamaga (2023)	2	2	2	2	2	2	12	High
Wilckens et al. (2023)	2	2	2	2	2	2	12	High
Žnidaršič et al. (2021)	1	2	2	1	2	2	10	High

Source: Author’s compilation

Table A2: Quality assessment of qualitative studies

Author (year)	Data analysis (0-2)	Credibility (0-2)	Total (0-4)	**Quality**
Urbaniak & Wiktorowicz (2014)	1	1	2	Moderate
Siivonen & Isopahkala-Bouret (2016)	2	2	4	High
Hennekam (2015)	2	2	4	High

Source: Author's compilation

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Factors Affecting the Willingness to Pay for Organic Food Among Generation Z Students in Hanoi, Vietnam: The Mediating Role of Awareness*

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Abstract

Despite the ongoing low demand for organic food in Vietnam, consumption of organic products is gradually increasing. There is a positive correlation between awareness of organic food benefits and the willingness to pay among Vietnamese youth. The growing interest in organic products among Generation Z students contributes to more sustainable consumer behavior, as well as to the promotion of overall health and environmental sustainability in Vietnam. The study aims to analyze the factors affecting the willingness to pay for organic food among Generation Z students in Hanoi, with a particular focus on the mediating role of awareness. The PLS-SEM technique was used to analyze data collected through direct interviews with 534 students from five universities in Hanoi using a structured questionnaire. The research results indicate that awareness of organic food has the greatest influence on willingness to pay for organic food, followed by knowledge of organic products, and health concerns. The findings also reveal that the direct relationship between environmental concerns and willingness to pay for organic food is not statistically significant. Based on these insights, the authors propose several recommendations for policymakers and businesses promoting

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organic food consumption in the Vietnamese market. This study contributes to the existing literature by highlighting the mediating role of awareness in the relationship between various factors and willingness to pay for organic food. The relevance and value of this research are underscored by its potential impact on promoting organic food consumption among Generation Z in emerging markets.

Keywords: *awareness, consumer behavior, health consciousness, organic food, willingness to pay*

JEL classification: *D12, I12, M31, Q13*

1. Introduction

The increasing awareness of environmental issues and the growing consumer interest in organic food, along with a willigness to invest in organic attributes, have prompted corporations to concentrate on organic marketing, driving significant transformations and advancements (Lavuri, 2022; Parashar et al., 2023). The rise of organic product development is essential to an emerging contemporary marketing paradigm, in which consumers prioritize comprehending the benefits of organic products before making purchasing decisions (Nguyen & Dekhili, 2019; Thøgersen et al., 2016).

Generation Z is the demographic cohort succeeding Millennials and preceding Generation Alpha. Individuals belonging to Generation Z were born in the mid-to-late 1990s to early 2010s, more specifically, from 1997 to 2012. The characteristics associated with this generation shape their product preferences and purchasing behaviors. According to Jílková and Králová (2020), Generation Z allocates a larger share of their spending to non-alcoholic food and beverages compared to Generations X and Y, with these items ranking third among the most frequently purchased products. Moreover, Gen Z individuals who actively engage in eco-friendly practices are more inclined to consume organic food (Lockie et al., 2002). Additionally, Lavuri et al. (2021) argue that factors such as knowledge, environmental consciousness, attitudes, and purchase intentions exert varying degrees of influence on the green buying behavior of Generation Z compared with Generation Y. In Vietnam, the Gen Z population reached around 15 million in 2020, accounting for approximately 19% of the working-age population (Nguyen & Nguyen, 2020), and is projected to approach nearly one-third by 2025 (Nguyen & Vo, 2023). Students represent a distinct subgroup within Generation Z and are characterized by higher levels of education and, consequently, potentially greater knowledge and awareness than other members of their cohort.

Although actual demand remains relatively low, the potential for organic products in Vietnam is increasing. (Hoang et al., 2022; Lavuri, 2022). Previous research has emphasized the importance of comprehending the underlying motivations for purchasing organic products among Vietnamese consumers (Ngan & Khoi, 2022;

Nguyen et al., 2019; Nguyen & Vo, 2023). While numerous studies explore factors influencing willingness to pay (WTP) for organic food, including health concerns, knowledge, and environmental concerns, there is a dearth of research focusing on the mediating role of awareness, particularly among Generation Z students in an emerging market context like Vietnam (Firoozzare et al., 2024; Nguyen et al., 2025; Pham et al., 2023). Understanding how initial concerns translate into actual WTP through awareness is essential for bridging the gap between positive attitudes and actual purchase behavior.

Accordingly, the primary objective of this study is to identify the key factors that influence WTP for organic food among Generation Z students in Hanoi, with a specific focus on the mediating role of awareness of organic food. Based on these insights, the study aims to provide recommendations for policymakers and businesses seeking to strengthen organic food consumption strategies.

This research paper is structured as follows: the first section comprises an introduction into the topic of the paper. The second section presents the literature review and hypothesis development. The third section describes the research methodology. The fourth section reports the findings, which is followed by the discussion in the fifth section. The final, sixth section concludes with policy implications.

2. Literature review

This section reviews the existing literature relevant to the study and outlines the theoretical foundations that underpin the research. It synthesizes key concepts and prior findings related to the topic and establishes the framework guiding the analysis in this study.

2.1. Theoretical framework

The Stimulus-Organism-Response (S-O-R) paradigm provides the theoretical foundation for understanding the decision-making process of Generation Z consumers in this study. The S-O-R framework is a core component of the Theory of Consumer Behavior. It proposes that environmental stimuli (S) affect the internal state of the organism (O), which subsequently shapes behavioral responses (R) (Talwar et al., 2021). In the context of this study, health concerns, environmental concerns, and knowledge act as external and internal stimuli (S) that activate consumers' cognitive processing. Awareness of organic food represents the organism (O) – the internal cognitive evaluation and recognition of value. Finally, WTP represents the behavioral response (R). This theoretical lens provides the necessary justification for the mediating role of awareness: stimuli alone are often insufficient to trigger a purchase decision (WTP) unless they are processed through consumers' awareness, transforming latent concerns into active purchase motivations.

2.2. Willingness to pay for organic food

WTP is defined as the maximum price a consumer is prepared to pay for a given quantity of goods or services (Katt & Meixner, 2020). Unlike conventional products, organic food often carries a price premium due to its specific production standards. However, WTP is not uniform; it varies significantly depending on the country, product category, and supply chain characteristics. In developed markets, WTP is often driven by established lifestyle preferences and strong consumer trust in certification labels (Gundala & Singh, 2021). Conversely, in emerging markets such as Vietnam, consumers are highly price-sensitive, and their WTP is often constrained by skepticism regarding the authenticity of organic claims (Nguyen & Dekhili, 2019). In addition, WTP differs depending on product category: consumers are generally willing to pay more for organic fresh produce (vegetables, milk) due to direct health implications compared to processed dry goods. Therefore, understanding WTP in the Vietnamese context requires examining localized drivers, including specific health concerns and the level of product awareness among young consumers (Minh Ngo et al., 2013).

2.3. Factors influencing willingness to pay for organic food

This section discusses the key factors that influence consumers' willingness to pay for organic food. It focuses on individual-level determinants identified in prior studies, with particular attention to their roles in shaping purchasing decisions in the context of organic food consumption.

2.3.1. Awareness of organic food

Awareness of organic food refers to consumers' recognition and understanding of the distinct attributes (e.g. safety, nutritional value, labels) that differentiate organic products from conventional ones (Yang et al., 2014). Within the S-O-R framework, awareness acts as a cognitive filter. Previous studies in emerging markets such as Pakistan and Turkey have demonstrated a positive correlation between consumer perception/awareness and their WTP (Asif et al., 2018). When consumers possess a high level of awareness, they perceive the value of the product to outweigh the cost, thereby increasing their WTP. Based on this theoretical reasoning, the following hypothesis is developed:

> H1: *Awareness of organic food positively influences willingness to pay for organic food among Generation Z students in Hanoi.*

2.3.2. Environmental concerns

Environmental concern reflects consumers' awareness of and emotional detachment from environmental degradation, food safety, and sustainable consumption (Ghvanidze et al., 2017; Stern, 2002). Consumers with higher levels of environmental concern are more likely to seek information about organic food, understand its benefits, and recognize its role in promoting health and environmental sustainability, thereby enhancing their overall awareness of organic food products (Barrera-Verdugo & Durán-Sandoval, 2024). While some studies report a direct link between environmental concern and WTP (Bhattarai, 2019; Liang et al., 2024), others indicate that this relationship is complex. Consumers may care about the environment, but may not be willing to pay a premium unless they explicitly understand how a specific product contributes to sustainability (Ramalingam & Anuradha, 2021; Nguyen et al., 2025). Based on this reasoning, the following hypotheses are developed:

> H2: *Environmental concern positively influences awareness of organic food among Generation Z students in Hanoi.*

> H3: *Environmental concern positively influences willingness to pay for organic food among Generation Z students in Hanoi.*

2.3.3. Health consciousness

Health consciousness is widely regarded as one of the primary drivers of organic food consumption (Parashar et al., 2023). Consumers with higher levels of health consciousness tend to pay closer attention to food quality, nutritional value, and potential health risks associated with conventional food products (Parashar et al., 2023). As a result, they are more motivated to seek information about organic food, understand its health-related benefits, and distinguish it from non-organic alternatives, thereby increasing their overall awareness of organic food products. Moreover, consumers often view organic food as an investment in personal well-being (Ramalingam & Anuradha, 2021). According to the Theory of Consumer Behavior, individuals seek to maximize utility; thus, those with higher levels of health consciousness perceive greater utility in organic food, which justifies paying a higher price (Effendi et al., 2015; Jahangir et al., 2009). Based on these insights, the following hypotheses are proposed:

> H4: *Health consciousness positively influences awareness of organic food among Generation Z students in Hanoi.*

> H5: *Health consciousness positively influences willingness to pay for organic food among Generation Z students in Hanoi.*

2.3.4. Knowledge of organic food

Knowledge refers to the information consumers possess regarding organic farming processes and standards. Consumers who possess greater knowledge about organic food are more capable of evaluating its quality, safety, and environmental advantages (Nautiyal & Lal, 2025). This understanding reduces uncertainty and perceived risk related to higher prices. As a result, informed consumers are more likely to appreciate the added value of organic food and demonstrate a stronger willingness to pay a price premium compared to those with limited knowledge. (Mahmud, 2024; Singh & Verma, 2017). Aryal et al. (2009) argue that informed consumers are more likely to appreciate the complexity of organic farming, making them more accepting of higher prices. In the context of Generation Z students, who have access to higher education, this knowledge acts as a critical stimulus that shapes purchasing behavior (Gundala & Singh, 2021). This disparity in knowledge and consumption patterns underscores the need for targeted educational and marketing strategies to promote organic food in regions with lower levels of consumer awareness. Based on this reasoning, the following hypotheses are developed:

> H6: *Knowledge of organic food positively influences awareness of organic food among Generation Z students in Hanoi.*
>
> H7: *Knowledge of organic food positively influences willingness to pay for organic food among Generation Z students in Hanoi.*

2.4. Mediating role of awareness

A critical gap in the existing literature concerns the explanation of how consumer concerns translate into action. Using the S-O-R model, we argue that awareness plays a mediating role.

Firstly, health consciousness (S) motivates consumers to seek information, thereby increasing their awareness (O). This heightened awareness enables them to verify whether a product meets their health expectations, ultimately increasing their WTP (R) (Talwar et al., 2021; Rana & Paul, 2017).

Secondly, product knowledge and awareness of their benefits play a role in determining consumers' WTP for these products (Mahmud, 2024; Singh & Verma, 2017). Knowledge serves as a foundation, but awareness is the active application of that knowledge in a specific purchasing context. Knowledgeable consumers are more likely to be aware of specific product attributes, which justifies paying a premium (Effendi et al., 2015; Mahmud, 2024; Singh & Verma, 2017).

Thirdly, environmental concern is often abstract. For this concern to influence WTP, it must be translated into concrete understanding through awareness. Consumers must first be aware that organic farming is eco-friendly before their environmental values can shape their WTP (Sesini et al., 2023; Newton et al., 2015; Ramalingam & Anuradha, 2021). Without awareness, environmental concern remains a latent attitude without behavioral consequences (Sesini et al., 2023). Based on this reasoning, the following hypotheses are proposed:

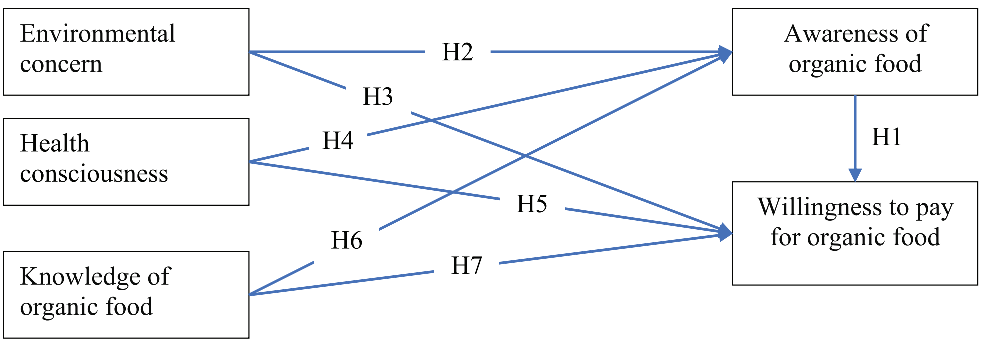
> H8: *Awareness of organic food positively mediates the relationship between health concerns and willingness to pay.*

> H9: *Awareness of organic food positively mediates the relationship between knowledge and willingness to pay.*

> H10: *Awareness of organic food positively mediates the relationship between environmental concerns and willingness to pay.*

Finally, the research model is proposed as follows.

Figure 1: The proposed conceptual model



Source: Authors' illustration

3. Methodology

This section presents the methodology adopted in this study. It describes the research design and the procedures used to collect and analyze data, with a particular focus on the measurement instruments employed to ensure the reliability and validity of the research findings.

3.1. Measurement instrument

To ensure content validity of the research instrument, all measurement items for the constructs were adapted from established scales in previous studies and subsequently modified to fit the context of organic food consumption in Vietnam.

Each item was assessed using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Before administering the official survey, a rigorous translation and validation procedure was implemented. The original English items were translated into Vietnamese and reviewed by a panel of six lecturers from the Vietnam National University to ensure terminological accuracy and cultural appropriateness. A pre-test with five students was then conducted to verify the clarity, readability and overall comprehensibility of the questionnaire. The final measurement scales and their corresponding sources are presented in detail in Table 1.

Table 1: Variables, items, and explanations used in the PLS-SEM

Item	Explanation	Reference
Willingness to pay		
WTP 1	I am considering to pay for organic food.	Aryal et al., 2009; Krystallis & Chryssohoidis, 2005; Jahangir et al., 2009
WTP 2	I intend to pay for organic food.	
WTP 3	There is a strong probability that I will pay more for organic food.	
Awareness of organic food		
AWE 1	I can recognize organic food.	Rana & Paul, 2017; Kapuge, 2016; Sesini et al., 2023
AWE 2	I comprehend the concept of organic food.	
AWE 3	I am acquainted with the term "*organic food*".	
Health consciousness		
HEC 1	Organic food consumption contributes to health benefits.	Magnusson et al., 2003; Gan et al., 2014; Ghvanidze et al., 2017
HEC 2	I carefully select food to ensure good health.	
HEC 3	I perceive myself as a health-conscious consumer.	
HEC 4	I frequently think about health-related issues.	
Knowledge of organic food		
KNO 1	I can distinguish between organic food and non-organic food.	Aryal et al., 2009; Singh & Verma, 2017
KNO 2	I am knowledgeable about the production process of organic food.	
KNO 3	I understand that organic food is safer to consume.	
Environmental concerns		
ENC 1	The environmental balance is delicate and can be easily disrupted.	Magnusson et al., 2003; Ramalingam & Anuradha, 2021; Asif et al., 2018
ENC 2	Humans are severely abusing the environment.	
ENC 3	Humans must maintain equilibrium with the environment to ensure survival.	
ENC 4	Human intervention in the environment often leads to serious consequences.	

Source: Authors' constructions

3.2. Sampling design and data collection

To ensure sample representativeness while maintaining logistical feasibility, this study employed a multi-stage random sampling technique rather than simple random sampling.

Stage 1 (Cluster Selection): From a list of 21 major universities in Hanoi, five universities were randomly selected to serve as primary sampling units (clusters) using the randomization tool on random.org. These selected universities were: Vietnam National University of Agriculture, Banking Academy, Posts and Telecommunications Institute of Technology, Electric Power University, and National Economics University.

Stage 2 (Participant Selection): Within each selected university, the research team collaborated with administrative offices to access student lists. Based on these lists, classes and individual students were randomly selected. Data were then collected through direct, face-to-face distribution of structured questionnaires to students, where the research team met participants in person and administered the survey.

Data collection was conducted from December 2023 to March 2024 via a face-to-face questionnaire approach. This direct interaction ensured a high response rate and data quality. Ultimately, a total of 534 valid questionnaires were collected and used for the final analysis.

3.3. Data analysis method

The collected data were first processed using Microsoft Excel 2013 and subsequently analyzed using SmartPLS 3.5 software. The study employed Partial Least Squares Structural Equation Modeling (PLS-SEM), a method suitable for exploratory research and complex models with non-normal data distributions. Following the two-step procedure recommended by Hair et al. (2019), the analysis proceeded as follows. Firstly, the measurement model was assessed. The reliability and validity of the constructs were examined using outer loadings, Cronbach's alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). Discriminant validity was assessed using the Fornell-Larcker criterion. Secondly, the structural model was assessed. The hypothesized relationships and the mediating role of awareness were tested using the bootstrapping method with 5000 subsamples to determine the significance of the path coefficients.

Data collection took place from December 2023 to March 2024 through a structured questionnaire. A total of 534 valid responses were obtained and included in the final analysis. The sample size is described in Table 2.

Table 2: Sample collected in different universities

No.	University	Frequency (individuals)	Percentage (%)
1	Electric Power University	93	17.41
2	National Economics University, Hanoi	110	20.60
3	Vietnam National University of Agriculture	118	22.10
4	Banking Academy	98	18.35
5	Posts and Telecommunications Institute of Technology	115	21.54
Total		534	100.00

Source: Authors' calculations

4. Results

This section presents the empirical findings of the study. It begins with a description of the respondents' demographic and general profiles, followed by the key results derived from the data analysis.

4.1. Profiles of the respondents

The demographic profiles of the 534 respondents indicate a balanced distribution across gender, income levels, and fields of study, as presented in Table 3.

Table 3: The demographic profiles of the respondents

Criterion		Frequency (people)	Percentage (%)
Gender	Female	268	50.19
	Male	266	49.81
Income (million VND/ month, including family remittances and extra income)	Below 5	195	36.52
	From 5 to 10	210	39.33
	Above 10	129	24.16
Field of study	Social Sciences and Humanities	132	24.72
	Technology and Engineering	124	23.22
	Economics and Business Administration	162	30.34
	Other, such as Education, Arts, Foreign Languages...	116	21.72

Criterion		Frequency (people)	Percentage (%)
Student	Year 1	125	23.41
	Year 2	141	26.40
	Year 3	129	24.16
	Year 4 and above	139	26.03
Total		534	100.00

Note: 1 USD = 24,470 VND according to Vietcombank on 8th March 2024.

Source: Authors' calculations

Regarding the descriptive statistics of the measurement items, Table 4 shows that the mean values range from 3.225 to 4.395, with standard deviations between 0.702 and 0.959, reflecting consistent responses. Importantly, the skewness and kurtosis values fall within the recommended range of -2 to +2, confirming that the data distribution is sufficiently normal for PLS-SEM analysis without significant outliers.

Table 4: Descriptive statistics for variables

No.	Items	Explanation	Mean	Median	Standard deviation	Excess kurtosis	Skewness	Cramér-von Mises p value
1	AWE1	I can recognize organic food.	4.049	4	0.853	0.081	-0.619	0
2	AWE2	I comprehend the concept of organic food.	3.875	4	0.915	-0.208	-0.456	0
3	AWE3	I am acquainted with the term "*organic food*".	4.395	5	0.729	1.587	-1.175	0
4	KNO1	I can distinguish between organic food and non-organic food.	3.395	3	0.95	-0.005	-0.243	0
5	KNO2	I am knowledgeable about the production process of organic food.	3.225	3	0.959	-0.485	0.036	0
6	KNO3	I understand that organic food is safer to consume.	3.633	4	0.863	-0.095	-0.214	0

No.	Items	Explanation	Mean	Median	Standard deviation	Excess kurtosis	Skewness	Cramér-von Mises p value
7	WTP1	I am considering to pay for organic food.	4.058	4	0.751	1.052	-0.761	0
8	WTP2	I intend to pay for organic food.	4.037	4	0.822	0.374	-0.677	0
9	WTP3	There is a strong probability that I will pay more for organic food.	3.936	4	0.834	-0.011	-0.481	0
10	HEC1	Organic food Consumption contributes to health benefits.	3.908	4	0.801	0.702	-0.601	0
11	HEC2	I carefully select food to ensure good health.	3.856	4	0.883	0.14	-0.501	0
12	HEC3	I perceive myself as a health-conscious consumer.	3.918	4	0.889	0.603	-0.799	0
13	HEC4	I frequently think about health-related issues.	3.757	4	0.912	0.446	-0.568	0
14	ENC1	The environmental balance is delicate and can be easily disrupted.	4.296	4	0.702	1.602	-0.909	0
15	ENC2	Humans are severely abusing the environment.	4.169	4	0.794	1.198	-0.895	0
16	ENC3	Humans must maintain equilibrium with the environment to ensure survival.	3.856	4	0.889	0.449	-0.628	0
17	ENC4	Human intervention in the environment often leads to serious consequences.	4.066	4	0.792	0.958	-0.776	0

Source: Authors’ calculations

4.2. Assessment of the measurement model

The measurement model was evaluated based on internal consistency reliability, convergent validity, and discriminant validity (Hair et al., 2019). First, indicator reliability was assessed using outer loadings. As shown in Table 5, items AWE3 and HEC1 were removed because their outer loadings fell below the recommended threshold of 0.70. All remaining items demonstrated loadings above 0.708. Second, internal consistency reliability was confirmed as all Cronbach's alpha and Composite Reliability (CR) values exceeded the 0.70 threshold. Third, convergent validity was established, with Average Variance Extracted (AVE) values surpassing 0.50 for all constructs, ranging from 0.625 to 0.784, which can be seen in Table 5.

Table 5: Assessment of the measurement model

Items	Outer loading	Cronbach's alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Awareness of organic food		0.726	0.879	0.784
AWE1	0.901			
AWE2	0.870			
Environmental concerns		0.801	0.870	0.625
ENC1	0.762			
ENC2	0.813			
ENC3	0.810			
ENC4	0.778			
Health consciousness		0.778	0.872	0.694
HEC2	0.838			
HEC3	0.793			
HEC4	0.866			
Knowledge of organic food		0.724	0.845	0.646
KNO1	0.807			
KNO2	0.853			
KNO3	0.748			
Willingness to pay		0.858	0.915	0.782
WTP1	0.800			
WTP2	0.929			
WTP3	0.918			

Source: Authors' calculations

Discriminant validity was assessed using the Fornell-Larcker criterion, as can be seen in Table 6. The results show that the square root of the AVE for each construct (diagonal values) exceeds its highest correlation with any other construct in the model. This confirms that the constructs are empirically distinct (Hair et al., 2019).

Table 6: Discriminant validity test results

Items	Knowledge of organic food	Awareness of organic food	Environmental concerns	Health consciousness	Willingness to pay
Knowledge of organic food	0.804				
Awareness of organic food	0.433	0.885			
Environmental concerns	0.452	0.459	0.791		
Health consciousness	0.440	0.497	0.450	0.833	
Willingness to pay	0.519	0.533	0.372	0.444	0.884

Source: Authors' calculations

The results of the hypothesis testing are presented in Table 7, and the corresponding path diagram illustrating both direct and indirect effects among the constructs is presented in Figure 2. The findings highlight the significant mediating role of awareness of organic food in shaping consumers' WTP. Although the direct effect of environmental concerns on WTP is not significant ($\beta = 0.023$, $p = 0.650$), its indirect effect through awareness is significant ($\beta = 0.075$, $p < 0.001$), indicating that heightened awareness can effectively translate environmental concerns into a stronger willingness to pay. Similarly, health consciousness and knowledge of organic food exert both direct and indirect effects on WTP. The significant indirect effects through awareness ($\beta = 0.098$, $p < 0.001$ and $\beta = 0.061$, $p = 0.005$, respectively) further emphasize the importance of consumer awareness as a bridge between these factors and payment behavior. These results suggest that awareness serves as a key mechanism that amplifies the impact of consumers' environmental and health motivations, as well as their knowledge, on their willingness to pay for organic products.

Table 7: Path coefficient and total indirect effect of the structural model

Path Coefficient	Original sample (Beta)	Sample mean (M)	Standard deviation (STDEV)	t-statistics (O/STDEV)	p-values
Direct effects					
Awareness of organic food → Willingness to pay	0.319	0.318	0.057	5.613	0.000
Environmental concerns → Awareness of organic food	0.234	0.238	0.051	4.567	0.000
Environmental concerns → Willingness to pay	0.023	0.025	0.051	0.454	0.650
Health consciousness → Awareness of organic food	0.307	0.306	0.043	7.135	0.000
Health consciousness → Willingness to pay	0.139	0.141	0.050	2.750	0.006
Knowledge of organic food → Awareness of organic food	0.192	0.190	0.053	3.637	0.000
Knowledge of organic food → Willingness to pay	0.310	0.309	0.058	5.331	0.000
Indirect effects					
Environmental concerns → Awareness of organic food → Willingness to pay	0.075	0.075	0.020	3.827	0.000
Health consciousness → Awareness of organic food → Willingness to pay	0.098	0.097	0.021	4.691	0.000
Knowledge of organic food → Awareness of organic food → Willingness to pay	0.061	0.061	0.022	2.843	0.005

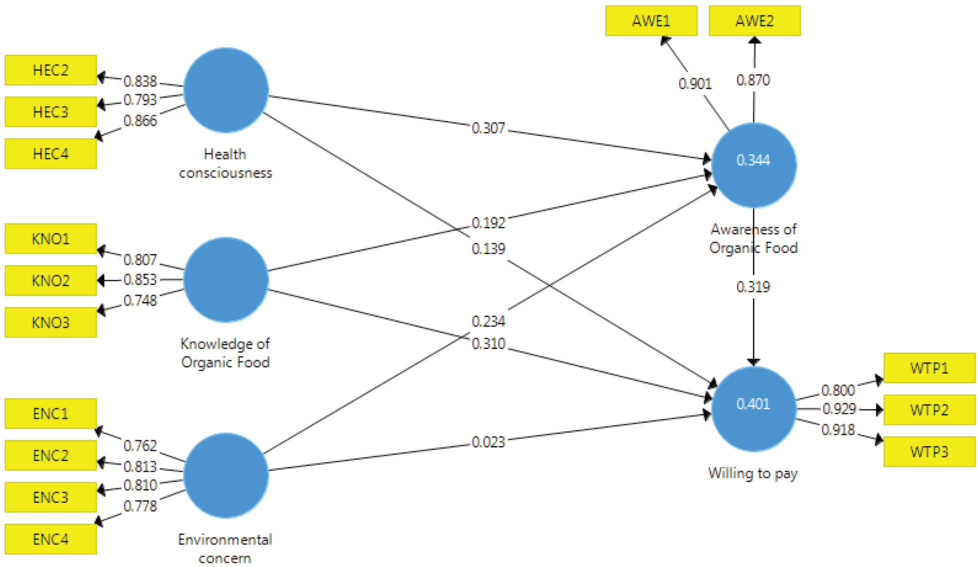
Source: Authors' calculations

4.3. Assessment of the structural model

The structural model was assessed to test the hypothesized relationships. The model's explanatory power is reflected in the R^2 values (Figure 2): it accounts for 34.4% of the variance in awareness of organic food (R^2 =0.344) and 40.1% of the variance in WTP (R^2=0.401), indicating moderate predictive accuracy.

Hypothesis testing (direct effects): The bootstrapping results (5000 subsamples) presented in Table 7 indicate that awareness (β=0.319, p<0.001), knowledge (β=0.310, p<0.001), and health consciousness (β=0.139, p=0.006) exert significant positive direct effects on WTP. Thus, hypotheses H1, H2, and H3 are supported. In contrast, environmental concerns do not have a significant direct impact on WTP (β=0.023, p=0.650), leading to the rejection of the hypothesis H4.

Figure 2: Structural model



Source: Authors' illustration

Mediation analysis (indirect effects): The study specifically examines the mediating role of awareness. The results confirm significant indirect effects:

- Health consciousness → Awareness → WTP ($\beta=0.098$, $p<0.001$).
- Knowledge → Awareness → WTP ($\beta=0.061$, $p=0.005$).
- Environmental concerns → Awareness → WTP ($\beta=0.075$, $p<0.001$).

These findings support hypotheses H5, H6, and H7. Notably, although environmental concerns have no direct effect on WTP, it exerts a significant positive indirect effect through awareness, highlighting a full mediating role of awareness in this specific relationship.

5. Discussion

The primary objective of this study was to decode the mechanism driving the WTP for organic food among Generation Z students in Hanoi. Interpreted through the lens of the S-O-R framework, the findings confirm that awareness of organic food functions as the critical *Organism* that processes external *Stimuli* (health, knowledge, environmental concerns) to generate the behavioral *Response* (WTP).

The empirical results identify awareness of organic food as the most influential determinant of WTP. This aligns with the findings of Yang et al. (2014) and Asif et al.

(2018), who argue that in emerging markets, consumer confidence depends heavily on their ability to recognize and comprehend product attributes. For Generation Z, an information-rich cohort, mere exposure to organic products is insufficient. They require a deeper, internalized awareness of certification standards, labeling cues, and specific benefits to justify the price premium. This supports the hypothesis H1 and reinforces the S-O-R premise: without the cognitive processing represented by the *Organism* (awareness), the purchase response is unlikely to occur.

One of the most intriguing findings of this study is the insignificance of the direct relationship between environmental concerns and WTP (H4 not supported), contrasted with a significant indirect effect through awareness (H7 supported). This pattern reflects a common gap in green consumerism in developing nations: students may possess high environmental concerns (as shown in the high descriptive mean), but this abstract concern does not automatically translate into financial commitment. This contradicts simpler models described by Bhattarai (2019), but resonates with the complex decision-making processes explained by Ramalingam and Anuradha (2021). The results suggest that environmental concerns influence WTP only when activated through specific product awareness. In other words, Gen Z consumers need to be aware of how a particular organic product benefits the environment before they are willing to pay for it. Awareness thus acts as a bridge that converts abstract environmental values into concrete purchasing actions.

Consistent with the Theory of Consumer Behavior, both knowledge of organic food and health consciousness exert strong positive effects on WTP, directly and indirectly. The substantial impact of knowledge corroborates the findings of Singh and Verma (2017), suggesting that as students gain more factual information about organic farming processes, their skepticism decreases, and their valuation of the product increases. Similarly, the results reaffirm that egoistic motives (personal health) often outweigh altruistic motives (environment) in driving WTP. As noted by Parashar et al. (2023), health is perceived as a direct personal investment. However, this study adds an important nuance: even health-conscious students rely on awareness to verify that an organic product genuinely delivers the promised health benefits, which supports the hypothesis H5.

In summary, the findings provide empirical evidence that for Vietnamese Gen Z, awareness is the gatekeeper. Knowledge and concerns provide the fuel, but awareness is the engine that drives the WTP.

6. Conclusions, implications, and research limitations

This section summarizes the main findings of the study and presents the conclusions drawn from the analysis. It also discusses the theoretical and practical implications of the results, as well as the limitations of the research and suggestions for future studies.

6.1. Conclusion

This study set out to examine the factors influencing the WTP for organic food among Generation Z students in Hanoi through the S-O-R framework. Analysis of data from 534 students using PLS-SEM yields two central conclusions. First, awareness of organic food emerges as the most powerful determinant of WTP, exerting the strongest impact both directly and as a mediator. This underscores that for young consumers in an emerging market, the cognitive process of understanding product attributes is a prerequisite for monetary commitment. Second, the study reveals a critical nuance in green consumerism: environmental concerns alone are insufficient to drive WTP. While environmental concerns do not directly trigger WTP, they significantly drive WTP when mediated through awareness. This indicates that Generation Z's broad concern for environmental issues only translates into purchasing behavior when they are specifically aware of how organic products contribute to environmental sustainability. By validating the full mediating role of awareness, this research fills a significant gap in the literature regarding consumer behavior in transition economies like Vietnam.

6.2. Practical implications

Drawing from the research findings, several practical implications are proposed, emphasizing the pivotal role of awareness in shaping consumer behavior towards organic food.

The first implication is for policymakers, given that health consciousness and knowledge are strong predictors of WTP. Public health initiatives should therefore extend beyond general encouragement and instead incorporate educational programs in universities that explicitly connect organic food consumption to long-term health benefits and (national) food safety standards. Policymakers should also consider establishing a transparent and easily accessible national database of certified organic producers to enhance the knowledge aspect and reduce skepticism among young consumers.

The second implication concerns business managers and marketers. The finding that environmental concerns have no direct impact on WTP serves as a wake-up call for marketing strategies. Simply labeling a product as eco-friendly is ineffective for this demographic. Instead, businesses and marketing strategies should focus on tangible awareness. Marketing messages should bridge the gap between abstract environmental concerns and concrete product benefits. Rather than relying on vague slogans, brands should use storytelling or QR codes to demonstrate exactly how their organic farming practices protect the soil or reduce emissions. This builds the awareness necessary to trigger the indirect path to WTP. Since awareness is the strongest driver of WTP, businesses must also justify the price premium by highlighting certification labels and nutritional facts on packaging. This approach aligns with Gen Z's high information-seeking tendencies and helps transform them from passive observers into active buyers.

6.3. Research limitations and future directions

While this study offers valuable insights, several limitations exist. The first limitation concerns the sample, which was restricted to university students in Hanoi. While students represent an important segment of Generation Z, their purchasing power differs from that of working young adults. Future research should therefore broaden the demographic scope to include older Gen Z individuals with independent incomes and extend data collection to other major cities, such as Ho Chi Minh City, or rural areas to enhance the generalizability of the findings. The seecond limitation refers to the model specification. The current model focused exclusively on psychometric constructs (health, environment, knowledge). It did not incorporate moderating demographic variables such as gender, monthly income, or academic background. Future studies should integrate these moderators to investigate whether the mediating role of awareness varies across different income groups, gender categories, or educational levels, providing a more nuanced and granular understanding of organic consumption behavior.

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Čimbenici koji utječu na spremnost na plaćanje organske hrane među studentima generacije Z u Hanoiju, Vijetnamu: Medijacijska uloga osviještenosti

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Sažetak

Unatoč niskoj potražnji za organskom hranom u Vijetnamu, potrošnja organskih proizvoda postupno raste. Postoji pozitivna korelacija između osviještenosti o prednostima organske hrane i spremnosti na plaćanje među vijetnamskom mladeži. Rastući interes studenata Generacije Z za organske proizvode doprinosi održivijem potrošačkom ponašanju te promicanju općeg zdravlja i ekološke održivosti u Vijetnamu. Cilj ovog istraživanja bio je analizirati čimbenike koji utječu na spremnost na plaćanje organske hrane među studentima Generacije Z u Hanoiju, s posebnim naglaskom na medijacijsku ulogu osviještenosti. Tehnika PLS-SEM korištena je za analizu podataka prikupljenih putem izravnih intervjua s 534 studenta s pet sveučilišta u Hanoiju, koristeći strukturirani upitnik. Rezultati istraživanja pokazuju da osviještenost o organskoj hrani ima najveći utjecaj na spremnost na plaćanje, nakon čega slijede znanje o organskim proizvodima i briga o zdravlju. Rezultati također otkrivaju da izravna veza između ekološke zabrinutosti i spremnosti na plaćanje nije statistički značajna. Na temelju ovih uvida, autori predlažu nekoliko preporuka za donositelje politika i poduzeća koja promiču potrošnju organske hrane na vijetnamskom tržištu. Ovo istraživanje doprinosi postojećoj literaturi isticanjem medijacijske uloge osviještenosti u odnosu između različitih čimbenika i spremnosti na plaćanje organske hrane. Relevantnost i vrijednost istraživanja dodatno su naglašene njegovim potencijalnim utjecajem na promicanje potrošnje organske hrane među pripradnicima Generacije Z na tržištima u razvoju.

Ključne riječi: *osviještenost, potrošačko ponašanje, briga o zdravlju, organska hrana, spremnost na plaćanje*

JEL klasifikacija: *D12, I12, M31, Q13*

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Friendship Paradox in Investment: How Diplomatic Proximity Affects FDI Inflows*

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Abstract

This study examines whether bilateral diplomatic proximity between Serbia and FDI-origin countries is positively or negatively associated with foreign direct investment (FDI) inflows. Using an augmented gravity model and a dynamic panel (System GMM) specification, it introduces a political proximity index (sScore) capturing foreign-policy similarity and geopolitical alignment alongside standard economic determinants; a squared term is added as an exploratory check for non-linearity. The static models show a statistically significant negative association between diplomatic proximity and FDI, which remains negative but only marginally significant in the dynamic specification. Serbia thus tends to attract more investment from countries that are not its closest diplomatic partners, a pattern the paper calls the "friendship paradox". A policy simulation illustrates the magnitude of this association, while the evidence on non-linearity is treated as secondary. The findings indicate that economic fundamentals and partner-country investment capacity are more decisive for FDI than diplomatic proximity, since Serbia's closest partners are often capital-scarce economies. The study concludes that diplomatic proximity should be analysed in conjunction with economic fundamentals and partner-country capital capacity, rather than presumed to increase investment on its own. These results are country-specific and should be interpreted as conditional associations rather than causal effects.

Keywords: *foreign direct investment, diplomatic proximity, geopolitical alignment, gravity model, Serbia*

JEL classification: *F21, F59, C33, O52*

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1. Introduction

Foreign direct investment (FDI) serves as a crucial driver of economic growth, fostering capital accumulation, technology transfer, and job creation in recipient economies. Within Europe, the European Union (EU) has long played a central role in facilitating cross-border investment by ensuring regulatory convergence, trade openness, and legal certainty (Polanco Lazo & Sauvé, 2018). However, FDI inflows are not solely determined by economic fundamentals; political and diplomatic relations between investors and host countries also influence investment decisions.

A growing body of research highlights the impact of bilateral diplomatic relations on FDI flows within Europe and beyond. While strong diplomatic ties may enhance investor confidence by reducing political risk and institutional uncertainty, diplomatic tensions may deter investment and lead to capital reallocation (Yılmaz, 2024). For Serbia, understanding how diplomatic alignment is associated with investment patterns is particularly relevant due to its geopolitical position and dual economic orientation. As a country striving for EU integration while maintaining strong ties with non-EU partners, such as China and Russia, Serbia navigates a complex diplomatic landscape that may shape investor confidence and FDI inflows. Diplomatic relations shape perceptions of political stability, regulatory predictability, and long-term economic cooperation, all of which are critical to investment decisions. The effects of diplomatic relations on FDI are especially pronounced in politically sensitive sectors such as energy, infrastructure, and high-tech industries, where investor confidence is closely tied to government relations and strategic alliances (Dollija & Teneqexhi, 2024).

Beyond direct economic incentives, diplomacy influences FDI through bilateral investment treaties, trade agreements, and institutional cooperation, which can reduce transaction costs and facilitate cross-border investment. Conversely, diplomatic tensions or misalignment with key investors may discourage capital inflows, particularly in economies where policy uncertainty remains a concern. For example, recent research suggests that diplomatic disputes can lead to the renegotiation or termination of trade agreements, affecting both the volume and composition of FDI inflows (Nwala, 2023). Additionally, economic diplomacy plays a crucial role in shaping investor sentiment, attracting long-term investment through enhanced cooperation between businesses and policymakers (Erokhin, 2024).

At the same time, the assumption that diplomatic closeness reliably translates into higher FDI is not self-evident. Existing gravity-based evidence suggests that bilateral FDI flows are strongly shaped by economic, macroeconomic and institutional fundamentals, including market size, distance, openness, inflation, interest rates, globalization and economic freedom (Mishra & Jena, 2019). This implies that diplomatic alignment may complement, but does not necessarily dominate, the economic determinants of capital flows. Moreover, international relations literature conceptualizes interstate relations as varying across different levels of rivalry, peace, and security cooperation, suggesting that political proximity should not be treated as a simple linear or binary condition (Diehl et al., 2021). In Serbia's case, a further structural consideration is compositional: the partners with which it maintains the closest diplomatic ties are predominantly neighbouring and politically allied economies that are themselves capital-scarce, whereas several of its largest investors are politically more distant. Taken together, these arguments raise the possibility of a *friendship paradox*, in which closer diplomatic relations are associated with lower rather than higher FDI inflows.

This study examines the relationship between the bilateral diplomatic proximity and FDI inflows to Serbia, considering both EU and non-EU investment sources. Using an augmented gravity model, we integrate a diplomatic proximity indicator, sScore, alongside traditional economic determinants to assess its association with FDI inflows. Given Serbia's strategic position between EU and non-EU economies, this research offers valuable insights into the extent to which diplomatic proximity complements or contrasts with economic determinants of investment. The inclusion of a dynamic panel model using the System Generalized Method of Moments (System GMM) estimator provides an additional robustness check by accounting for persistence in investment emphasis and potential endogeneity between diplomatic proximity and FDI flows.

Beyond the regression analysis, the study incorporates an illustrative policy simulation based on a common reference value of diplomatic proximity, sScore = 0.5, and a dynamic panel estimation using System GMM. The simulation is used to illustrate the substantive meaning of the estimated coefficient, while the GMM specification examines whether the main finding remains stable under a dynamic specification and whether the relationship contains exploratory non-linear elements.

Given these dynamics, an empirical analysis of Serbia's FDI patterns is essential to determine the extent to which diplomatic relations are associated with economic determinants in shaping investment decisions. By integrating political and economic factors, this study provides insights into the conditions under which diplomatic proximity may or may not correspond to stronger investment inflows.

Building on the gravity model of FDI and the strand of research emphasizing the investment-enhancing role of diplomacy, the study first tests the conventional expectation:

> H1: *Stronger bilateral diplomatic proximity between Serbia and FDI-origin countries is positively associated with FDI inflows.*

This hypothesis builds on theoretical foundations suggesting that political stability, diplomatic alignment, and institutional trust reduce transaction costs and enhance cross-border investment (Bevan et al., 2004; Kahouli & Maktouf, 2015). Given

Serbia's dual economic orientation between the EU and non-EU partners, this study examines whether diplomatic relations complement or override economic determinants in shaping FDI decisions.

Against this conventional expectation, and in line with the competing arguments outlined above, we formulate a second, directional hypothesis:

> H2: *Stronger bilateral diplomatic proximity between Serbia and FDI-origin countries is associated with lower FDI inflows.*

This hypothesis reflects the proposed *friendship paradox* introduced above, whereby investment decisions in Serbia's case may be dominated by economic fundamentals rather than by political closeness.

To avoid imposing a strictly linear interpretation, the empirical strategy also includes a quadratic term of diplomatic proximity in the dynamic specification. This extension is exploratory and is treated as supplementary to the main *friendship paradox* argument.

The remainder of the paper is organized as follows: Section 2 reviews the relevant literature. Section 3 presents the methodological approach and model specification. Section 4 describes the empirical data and provides the preliminary analysis of the dataset. Section 5 presents and discusses the main empirical results. Finally, Section 6 offers concluding remarks, implications, limitations and suggestions for future research.

2. Literature review

FDI has been extensively analysed through the lens of economic models, with the gravity model serving as one of the main frameworks for explaining bilateral investment flows (Bevan et al., 2004; Kahouli & Maktouf, 2015). In its basic form, the gravity approach assumes that investment between countries is shaped by economic size, geographic proximity, trade intensity and institutional conditions. While traditional gravity-based studies primarily emphasise economic fundamentals, more recent research has extended this framework by incorporating political, institutional and diplomatic factors. From this perspective, bilateral diplomatic relations may influence FDI by reducing uncertainty, lowering transaction costs and strengthening investor confidence (Musera, 2020). Well-established diplomatic relations may therefore contribute to higher investment inflows when they improve predictability and signal a stable environment for long-term economic cooperation.

Institutional theory complements this perspective by arguing that FDI is not driven only by market-related factors, but also by the stability and predictability of the host country's political and legal environment. Political risk remains an important concern for foreign investors, and diplomatic alignment may help mitigate such risks by improving institutional trust, facilitating communication between governments and supporting dispute-resolution mechanisms (Yılmaz, 2024). Economic diplomacy may also shape the investment climate through trade agreements, bilateral investment treaties, regulatory harmonisation and targeted investor engagement (Erokhin, 2024). In this sense, diplomacy can operate as a complementary institutional channel through which states seek to improve their attractiveness to foreign investors.

Empirical studies, however, present a mixed picture regarding the impact of diplomatic relations on FDI. Several studies support the view that strong diplomatic ties and economic diplomacy can enhance investment inflows, particularly in emerging markets where political stability and legal certainty are important for investor confidence (Dollija & Teneqexhi, 2024; Musera, 2020). Bilateral investment treaties, diplomatic missions, investment summits and high-level political visits may signal commitment to cooperation and reduce perceived risk. Recent evidence is consistent with this logic. Kim (2025), for example, finds that political visits can increase outward FDI to partner countries, although their effect depends on institutional and political conditions. Similarly, Li (2025) shows that senior leaders' diplomatic visits significantly promote Chinese outward FDI, while the effect on inward FDI to China is weaker and not always statistically significant. In a related vein, He et al. (2025) find that city-level diplomacy, in the form of international sister-city agreements, significantly increases inward FDI, with a stronger effect in larger and more market-oriented cities. These findings suggest that diplomacy can matter for investment, but also that its effect depends on institutional context, the direction of investment, and broader economic conditions.

At the same time, another strand of research challenges the assumption that diplomatic proximity is a dominant determinant of FDI. Gravity-based evidence suggests that bilateral FDI flows are strongly shaped by market size, distance, openness, macroeconomic stability, labour costs, taxation and other economic fundamentals (Mishra & Jena, 2019). This implies that diplomatic alignment may complement, but does not necessarily override, the economic logic of investment. In practice, investors may allocate capital to politically more distant countries when those countries offer stronger market opportunities, better cost conditions, regulatory advantages or access to strategic sectors. Diplomatic closeness should therefore not be treated as a sufficient condition for attracting FDI.

Recent literature on geopolitics and international business further reinforces this conditional interpretation and connects the analysis of FDI with political economy and international relations perspectives. Bhaumik et al. (2025) argue that geopolitical alignment influences both multinational enterprise strategies and host-country policy responses, but that its effect depends on countries' outside options, technology gaps and domestic political conditions. This means that geopolitical alignment does not operate mechanically. Rather, it shapes the strategic environment within which firms and governments make investment decisions. Using a gravity framework covering 234 economies over 2009-2021, Jurakovaite and Gaigaliene (2026) similarly find that bilateral cross-border investment is shaped by political-system and diplomatic proximity: flows tend to increase between allied countries and to decline toward more politically distant or less democratic recipients, even after controlling for conventional gravity determinants. Recent global investment evidence also points to a more uncertain and fragmented investment environment, in which geopolitical tensions, economic volatility and policy uncertainty increasingly affect investor confidence and cross-border capital flows (United Nations Conference on Trade and Development, 2025). Empirical evidence from Adil et al. (2026) further indicates that geopolitical risk can negatively affect FDI inflows, supporting the view that political and geopolitical factors matter for investment, but often through risk, uncertainty and strategic constraints rather than through diplomatic goodwill alone. In line with this, Wang et al. (2025) show that heightened geopolitical risk reduces FDI inflows even at the subnational level, underscoring that geopolitical factors often operate through risk and uncertainty.

Within the European context, regulatory convergence and trade openness have played a major role in attracting FDI, particularly within the EU framework (Polanco Lazo & Sauvé, 2018). The EU's common market policies, which reduce trade barriers and harmonise investment-related regulations, have encouraged cross-border capital flows. For non-EU countries such as Serbia, alignment with EU investment rules and market standards has been an important factor in attracting European investors (Kaeding & Udovič, 2024). Serbia's EU accession process, together with reforms aimed at increasing openness and improving the business environment, has therefore contributed to the country's investment attractiveness. However, Serbia's geopolitical position also makes it a specific case. While a substantial share of FDI comes from EU member states, Serbia has simultaneously developed political and economic relations with non-EU partners, including China and Russia. Filipović and Zakić (2025) describe this orientation as a *multi-vector* foreign policy, in which Serbia deliberately maintains parallel economic and political ties with the EU, China, Russia and other partners, with direct economic implications, including for the composition and origin of its FDI inflows. Some of these relationships involve state-backed or strategically motivated investment projects, especially in infrastructure, energy, and other politically sensitive sectors. In addition, recent research based on Delphi findings (Bugarčić et al., 2026) indicates that experts expect Serbia to maintain its cooperation with both the EU and China, and anticipate stronger growth in economic relations with China without significantly reducing the importance of the EU.

Diplomatic diversification has therefore become a visible feature of Serbia's external economic positioning. By maintaining relations with both EU and non-

EU partners, Serbia seeks to preserve access to different sources of capital, markets and strategic cooperation. However, the extent to which diplomatic diversification translates into sustainable FDI growth remains uncertain. Existing research does not sufficiently explain whether diplomatic proximity directly increases investment or whether FDI is shaped primarily by the economic capacity and strategic interests of partner countries.

Taken together, these strands point to a more ambivalent role of diplomacy than the conventional view implies. Diplomatic proximity may reduce uncertainty and support cooperation, but it may also be insufficient for attracting FDI when politically close partners lack investment capacity. In such circumstances, strong diplomatic alignment may coincide with lower investment potential rather than with higher capital inflows. This compositional logic provides the theoretical basis for the *friendship paradox* examined in this study, namely the possibility that stronger diplomatic relations between Serbia and partner countries are associated with lower FDI inflows. The paradox does not imply that diplomacy is irrelevant; rather, it suggests that diplomacy may be less decisive than economic fundamentals, partner-country investment capacity and the strategic priorities of investors.

This interpretation also connects to broader discussions of strategic neutrality and geopolitical flexibility. In small and transition economies positioned between competing political and economic blocs, maintaining room for manoeuvre across different partners may help preserve access to diverse sources of capital and reduce dependence on a narrow set of politically aligned partners. Recent international business research similarly emphasises that geopolitical alignment shapes FDI through the interaction between multinational enterprise strategies, host-country policy responses and countries' outside options (Bhaumik et al., 2025). From this perspective, excessive diplomatic closeness may entail potential costs if it narrows policy flexibility, increases institutional overdependence or signals alignment with partners that do not possess sufficient outward investment capacity. In the Serbian case, this logic is particularly relevant because political closeness and investment capacity do not necessarily coincide.

The possibility that the relationship between diplomatic proximity and FDI may also depart from strict linearity is treated as a secondary consideration. International relations literature conceptualises interstate relations as varying across different levels of rivalry, peace, and security cooperation, suggesting that political proximity should not be understood as a simple binary condition (Diehl et al., 2021). However, in the present study, the central theoretical claim is not that there is an optimal level of political alignment, but that the Serbian case may reveal a negative association between diplomatic closeness and FDI inflows. For this reason, the non-linear specification is included as an exploratory extension of the main analysis rather than as the core contribution of the paper.This study contributes to the literature by examining the relationship between bilateral diplomatic proximity and FDI inflows in Serbia, considering both EU and non-EU investment sources. By incorporating a diplomatic proximity indicator, examining the *friendship paradox* and exploring possible non-linear extensions, the paper provides country-specific evidence from a transition economy located between different geopolitical and investment spheres. In doing so, it extends the gravity model of FDI by integrating diplomatic and geopolitical dimensions, while also showing that political closeness does not necessarily translate into greater investment inflows.

3. Methodology and model specification

One of the first applied models that tried to explain bilateral trade flows is the gravity model, based on Newton's law of gravitation (Tinbergen, 1962). This model was later extended to investment flows. Similar to the pattern of international trade, the model assumes that the level of investments depends on the size of the economy, both the host and home countries of FDI. At the same time, the distance between the two countries will have a negative sign, which assumes that a greater inflow of investments can be expected from geographically closer countries. Several studies have empirically examined this relationship, extending the model by including new variables of interest to complement the model (Bevan et al., 2004; Globerman & Shapiro, 1999; Kahouli & Maktouf, 2015; Zwinkels & Beugelsdijk, 2010). Gravity modelling is also applied in assessing the effects of diplomatic activities on trade volume (Peternel & Grešš, 2021).

Our initial model, in addition to measuring the size of the domestic and partner economies and the distance between them, includes sScore as a proxy for bilateral diplomatic proximity between Serbia and FDI-origin countries. In this study, sScore is interpreted as an indicator of foreign-policy similarity and broader geopolitical alignment, rather than as a direct measure of investor perceptions, institutional trust or political stability. The baseline specification has the following form (Model 1):

$$\begin{aligned} lnFDI_{ijt} = \alpha + \beta_1 lnGDP_{it} + \beta_2 lnGDP_{jt} + \beta_3 distw_{ij} + \\ + \beta_4 Bilateral\_Diplomatic\_Relations_{ij} + \varepsilon_{ij} \end{aligned} \tag{1}$$

In order to extend the baseline specification, we include bilateral exports from Serbia to the country of capital origin and the degree of openness of the partner country, measured by the globalization index. Model 2 is specified as follows:

$$\begin{aligned} lnFDI_{ijt} = \alpha + \beta_1 lnGDP_{it} + \beta_2 lnGDP_{jt} + \beta_3 distw_{ij} + \\ + \beta_4 Bilateral\_Diplomatic\_Relations_{ij} + \beta_5 lnExport + \\ + \beta_6 Globalisation\_index + \varepsilon_{ij} \end{aligned} \tag{2}$$

Following Mishra and Jena (2019), Model 3 further includes variables that reflect the macroeconomic conditions of the host economy and may influence FDI inflows: GDP growth, inflation rate and taxes. The model has the following form:

$$\begin{aligned} lnFDI_{ijt} = \alpha &+ \beta_1 lnGDP_{it} + \beta_2 lnGDP_t + \beta_3 distw_{ij} + \\ &+ \beta_4 Bilateral\_Diplomatic\_Relations_{ij} + \beta_5 lnExport + \\ &+ \beta_6 Globalisation\_index + \beta_7 GDPgrowth + \beta_8 InflationRate + \\ &+ \beta_9 Taxes + \varepsilon_{ij} \end{aligned} \tag{3}$$

Considering the characteristics of the sample, which consists of countries from which Serbia received FDI during the observed period, we additionally include two dummy variables: EU member state and common border. Therefore, Model 4 has the following form:

$$\begin{aligned} lnFDI_{ijt} = \alpha &+ \beta_1 lnGDP_{it} + \beta_2 lnGDP_{jt} + \beta_3 distw_{ij} + \\ &+ \beta_4 Bilateral\_Diplomatic\_Relations_{ij} + \beta_5 lnExport + \\ &+ \beta_6 Globalisation\_index + \beta_7 GDPgrowth + \beta_8 InflationRate + \\ &+ \beta_9 Taxes + \beta_{10} EUdummy + \beta_{11} Borderdummy + \varepsilon_{ij} \end{aligned} \tag{4}$$

To extend the model's analytical relevance beyond estimation, we implement a policy simulation based on the final regression specification. The simulation evaluates a counterfactual scenario in which all countries are compared with a reference level of diplomatic proximity, sScore = 0.5. This reference value is not treated as an optimal level of alignment, but only as a common benchmark that allows us to illustrate how changes in diplomatic proximity would translate into predicted FDI changes under the estimated linear specification.

For each country, we compute the difference ΔsScore between the current and target alignment, and apply the estimated regression coefficient (β = −1.4872) from Model 4 FEE to calculate the projected effect on FDI inflows. The percentage change in FDI is calculated using the transformation appropriate for log-linear models, where the dependent variable is in natural logarithmic form. Following standard econometric interpretation (Wooldridge, 2013; Gujarati & Porter, 2009), the expected percentage change is derived using the formula:

$$\%\Delta FDI = (e^{\beta \cdot \Delta sScore} - 1) \cdot 100 \tag{5}$$

This simulation is used as an illustrative extension of the main regression result. It does not identify an optimal level of diplomatic alignment and does not, by itself, provide evidence of a non-linear relationship. Rather, it shows how the estimated negative association between diplomatic proximity and FDI would operate under a common counterfactual benchmark.

In addition to fixed effects models, the empirical strategy is extended using a dynamic panel estimation via the two-step System GMM method (Model 5). This approach allows for greater robustness by addressing the potential endogeneity between diplomatic alignment and FDI flows, as well as the temporal persistence in investment patterns. The model includes the lagged dependent variable to capture dynamic effects and, as an exploratory extension, includes both the linear and squared terms of diplomatic proximity to examine whether the relationship departs from strict linearity:

$$\begin{aligned} lnFDI_{ijt} = {} & \alpha + \beta_1 lnFDI_{ijt-1} + \beta_2 lnGDP_{it} + \beta_3 lnGDP_{jt} + \beta_4 distw_{ij} + \\ & + \beta_5 Bilateral\_Diplomatic\_Relations_{ij} + \\ & + \beta_6 Bilateral\_Diplomatic\_Relations^2{}_{ij} + \beta_7 lnExport + \\ & + \beta_8 Globalisation\_index + \beta_9 GDPgrowth + \beta_{10} InflationRate + \\ & + \beta_{11} Taxes_{ij} + \beta_{12} EUdummy + \beta_{13} Borderdummy + \varepsilon_{ij} \end{aligned} \tag{6}$$

By accounting for unobserved heterogeneity, autocorrelation and potentially endogenous regressors, the dynamic model provides an additional assessment of whether the core finding from the static specifications remains stable under a more demanding econometric specification. The squared term is included only to explore possible departures from linearity and is interpreted as supplementary to the main *friendship paradox* argument.

The empirical strategy is designed to identify conditional associations between diplomatic proximity and FDI inflows within an augmented gravity framework, rather than to establish a definitive causal effect. Although the dynamic specification helps address persistence in FDI inflows and potential endogeneity, the estimated relationship may still partly reflect broader geopolitical and structural characteristics of Serbia's investment profile.

4. Empirical data and analysis

The dependent variable is FDI inflow by country of origin, obtained from the National Bank of Serbia (NBS). Since NBS data by country of origin have been available from 2010, this year is used as the starting point of the analysis. The final empirical period is restricted to 2010-2018, because sScore data are available only up to 2018. Data on GDP, GDP growth, inflation rate and taxes are taken from the World Bank. Bilateral exports from Serbia to FDI-origin countries are obtained from the International Trade Centre. The Globalisation Index, used as a measure of partner-country openness, is taken from the KOF Swiss Economic Institute. Physical distance between capital cities and the dummy variables for EU membership and common border are taken from the CEPII dataset.

To provide additional context for Serbia's investment profile, we also describe selected FDI trends after 2018, although the econometric analysis itself is restricted to the 2010–2018 period due to the availability of sScore. The share of FDI in GDP ranged from around 3% in the early 2010s, increased to approximately 7-7.5% between 2018 and 2023, and declined slightly to around 5.5% in 2024. The composition of FDI by country of origin also changed substantially over time. In 2012, the Russian Federation accounted for a record 23% of FDI inflows, while EU-28 countries together accounted for 61.9%, led by Austria, the Netherlands, Luxembourg and France. China's share was only 0.1% in 2012, but increased markedly in later years, reaching 33.5% in 2022. By contrast, the share of EU-27 countries declined to around 33% in 2022, while the United Kingdom and Japan also became visible sources of investment. Russia's share declined from 23% in 2012 to 1.5% in 2022, reflecting the changing geopolitical and investment environment (National Bank of Serbia, 2024). Table 1 provides an overview of selected FDI inflows by country of origin. These descriptive trends are used only to contextualise Serbia's investment profile. They are not included in the econometric estimation, which is restricted to the 2010-2018 period due to the availability of sScore.

Table 1: FDI inflow by origin country, in millions USD

Year	EU-27	China	Russia	USA
2010	801.8	2.1	216.2	59.9
2011	2,724.5	18.9	488.5	37.0
2012	617.5	1.3	232.5	31.5
2013	1,064.9	22.2	189.7	22.1
2014	1,051.7	86.4	73.5	8.5
2015	1,509.6	66.5	96.4	38.5
2016	1,370.8	219.4	41.1	16.8
2017	1,701.7	179.2	170.4	37.6
2018	1,932.9	690.0	263.0	70.4
2019	2,309.9	344.9	576.8	185.7
2020	1,956.0	528.5	55.5	62.8
2021	1,762.4	630.4	39.9	105.6
2022*	401.0	491.5	30.4	56.7

Note: Data for 2022* is for the period Jan-Jun

Source: National Bank of Serbia (2024)

Diplomatic proximity between Serbia and FDI-origin countries is measured using sScore, developed by Signorino and Ritter (1999). In this study, sScore is used as a proxy for foreign-policy similarity and bilateral geopolitical alignment. The indicator ranges from -1 to 1, where higher values indicate greater similarity in the foreign-policy positions of two countries, while lower values indicate greater political distance From the perspective of FDI, sScore does not directly measure investor perceptions, institutional trust, regulatory quality or political stability, nor does it capture informal diplomatic channels, high-level political visits, sector-specific agreements, investment promotion activities or the intensity of day-to-day diplomatic engagement. Rather, it captures the broader political and geopolitical environment within which bilateral economic relations take place. For this reason, the variable is interpreted cautiously as an indicator of diplomatic proximity, not as a comprehensive measure of the overall quality and complexity of diplomatic relations.

Variables based on similar concepts have been used in different fields of international relations and political economy research (Dafoe, 2011; Diehl et al., 2021; Gartzke, 2007). However, their use in empirical analyses of economic relations, particularly bilateral investment flows, remains limited. This makes sScore relevant for the present study, but also requires a cautious interpretation of the results. The available period for this indicator is up to -2018, which determines the time span of the empirical analysis. Consequently, the econometric models are restricted to the period for which both FDI data and sScore are available.

Regarding sScore values in the observed period, Serbia records higher levels of diplomatic proximity with several neighbouring countries, such as North Macedonia, Montenegro and Bosnia and Herzegovina, as well as with some non-EU partners. By contrast, lower sScore values are observed for countries whose foreign-policy positions and geopolitical orientation differ more substantially from those of Serbia. This pattern is consistent with the interpretation of sScore as a measure of foreign-policy similarity and geopolitical alignment rather than as a direct measure of investment attractiveness or investor confidence.

Given that the analysis focuses on a single host country, Serbia, the findings should be understood as country-specific evidence from a transition economy with a specific geopolitical position, rather than as a general model of the diplomacy-FDI relationship across all economies.

The initial assumptions of the model were tested through a correlation matrix and a multicollinearity test. Table 2 gives insight into the level of correlation and multicollinearity (Variance Inflation Factor, VIF) test results. A positive correlation is present for all analysed variables except for distance and inflation, as expected. The positive sign of GDP indicates that a greater inflow of investments can be expected if the country of origin and the host country are larger. The distance is also in line with the assumption of the model that a smaller inflow of investments is expected from geographically distant countries. Among other variables, only inflation has a negative sign, and the highest degree of positive correlation is shown by exports, indicating the mutual connection between FDI and trade flows. Regarding multicollinearity risk, all VIF values are lower than 5, which indicates that there is no problem of multicollinearity in the model.

Table 2: Correlation and multicollinearity test

	Correlation with FDI	VIF
GDP_Srb	0.0352	1.87
GDP_partner_country	0.3235	3.14
distance	-0.1987	2.82
Bilateral_Diplomatic_Relations	0.0007	2.40
Export	0.4165	2.51
Globalisation index	0.3425	2.49
GDPgrowth	0.1501	1.29
InflationRate	-0.1075	4.14
Taxes	0.1503	3.97
EU_member_state	0.3711	2.75
common_border	0.0432	2.31

Source: Authors' calculations

5. Results and discussion

Table 3 shows the results according to the applied techniques and the defined model. Four separate models were tested using pooled ordinary least squares (POLS), while the fourth model was tested using fixed effect estimation (FEE) to ensure the robustness of the analysis (year and country fixed effects). The regression results follow the basic assumptions of the gravity model. The GDP of the FDI origin country is singled out as statistically significant across all observed models, while distance has a negative sign, although with a very small Beta coefficient. In contrast to evidence from the trade literature that uses the gravity approach, distance does not appear to be a significant obstacle to FDI.

The main variable of interest, bilateral diplomatic proximity, is negative and statistically significant in all specifications except Model 1. This finding should not be interpreted as evidence that diplomatic proximity independently causes lower FDI inflows. Rather, it indicates a conditional negative association between diplomatic proximity and FDI within the augmented gravity framework. In substantive terms, Serbia tends to receive larger investment inflows from countries that are not necessarily its closest diplomatic partners. This result is consistent with the proposed *friendship paradox*: politically and diplomatically closer partners may have limited outward investment capacity, while several politically more distant partners may invest more because of stronger economic fundamentals, larger capital bases, market strategies or sector-specific interests.

In the Serbian case, this pattern may partly reflect the composition of the country's diplomatic and investment relations. The finding therefore suggests that diplomatic proximity alone is not sufficient to explain FDI inflows, and that partner-country economic capacity remains central to the investment relationship.

Table 3: Estimates of augmented gravity models

Dependent variable: lnFDI	Model 1	Model 2	Model 3	Model 4	Model 4 FEE
lnGDP_Srb	0.6076	0.3053	-0.2078	-0.0826	
	(1.2624)	(1.1578)	(1.5683)	(1.5016)	
lnGDP_partner_country	0.5747***	0.2516***	0.2749***	0.4839***	
	(0.0676)	(0.0741)	(0.0741)	(0.0881)	
distance	-0.0003***	-0.0002***	-0.0002***	-0.0001**	-0.0001**
	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0001)
Bilateral_Diplomatic_Relations	-0.3205	-1.5719***	-1.4578***	-1.5114***	-1.4872***
	(0.5731)	(0.5486)	(0.5460)	(0.5253)	(0.5273)
lnExport		0.4527***	0.4278***	0.2815***	0.2713***
		(0.0654)	(0.0659)	(0.0772)	(0.0780)
Globalisation index		0.0825***	0.0779***	0.0226	0.0205
		(0.0148)	(0.0149)	(0.0199)	(0.0200)
GDPgrowth			0.1354**	0.1380**	0.1477**
			(0.0609)	(0.0583)	(0.0670)
InflationRate			-0.0097	-0.0259	-0.0564
			(0.0588)	(0.0564)	(0.0658)
Taxes			0.0136	0.0108	-0.0142
			(0.0400)	(0.0383)	(0.0415)
EU_member_state				1.3640***	1.3822***
				(0.3120)	(0.3135)
common_border				1.3992***	1.4053***
				(0.3819)	(0.3829)
Constant	-5.8229	-0.1776	11.8007	8.3967	7.0820***
	(30.9777)	(28.4149)	(37.8126)	(36.2285)	(2.6371)
F statistics	26.23***	31.57***	22.35***	22.80***	16.82***
R-squared	0.2429	0.3682	0.3845	0.4394	0.4440
Adj R-squared	0.2337	0.3566	0.3673	0.4201	0.4176

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Source: Authors' calculations

Regarding the remaining variables, bilateral exports are positively and statistically significantly associated with FDI inflows in all specifications in which they are included. This supports the view that investment and trade flows are closely connected, although the model does not allow us to infer the specific motives of foreign investors. The globalisation index loses statistical significance after additional controls are introduced, while inflation and taxes in the host country, Serbia, do not show a statistically significant association with FDI inflows. By contrast, real GDP growth is positively and significantly associated with FDI, suggesting that stronger domestic economic performance may be linked to higher investment inflows. The dummy variables for EU membership and common border are also positive and statistically significant, indicating that institutional proximity, regional connectedness and access to the European economic space remain relevant factors in Serbia's FDI profile. This finding is consistent with the broader interpretation that FDI inflows are shaped not only by diplomatic proximity, but also by economic size, trade links and structural characteristics of partner countries.

The findings do not support H_1, which proposed that stronger bilateral diplomatic proximity between Serbia and FDI-origin countries would be positively associated with FDI inflows. Instead, the results support H_2 and reveal a *friendship paradox*: within the estimated gravity framework, higher diplomatic proximity is associated with lower FDI inflows. This is the central empirical finding of the paper, as it shows that diplomatic closeness does not necessarily translate into investment attraction in the Serbian case. The result is consistent with the argument that FDI decisions are strongly shaped by economic fundamentals, such as market size, partner-country investment capacity and the broader business environment (Mishra & Jena, 2019).

This interpretation is further illustrated by the policy simulation presented in Table 4. The simulation compares selected countries with a common reference value of diplomatic proximity, sScore = 0.5. This value is not treated as an optimal or recommended level of diplomatic alignment, but as a benchmark that helps illustrate the substantive meaning of the estimated coefficient. For countries with low current sScore values, such as Israel (-0.168), the UAE (-0.165) and Singapore (-0.083), an increase toward the reference value is associated with a projected decline in FDI between approximately 58% and 63%. Conversely, for countries with very high sScore values, such as North Macedonia (0.906) and Bosnia and Herzegovina (0.873), a decrease toward the reference value is associated with a projected increase in FDI of approximately 74% to 83%. These simulated changes illustrate the practical magnitude of the *friendship paradox*: diplomatically closer partners are not necessarily Serbia's strongest sources of investment.

Table 4: Policy simulation results

Country	Current sScore	Change to 0.5	Estimated FDI Change (%)	Scenario
Israel	-0.168	+0.668	-63.0%	Increase to 0.5
UAE	-0.165	+0.665	-62.8%	Increase to 0.5
Singapore	-0.083	+0.583	-58.0%	Increase to 0.5
North Macedonia	0.906	−0.406	+82.9%	Decrease to 0.5
Bosnia and Herzegovina	0.873	−0.373	+74.3%	Decrease to 0.5

Note: The countries displayed in the table were selected as illustrative examples, representing those with the most extreme sScore values in the dataset.

Source: Authors' calculations

Overall, the policy simulation illustrates the practical magnitude of the *friendship paradox* identified in the main regression results. It shows that diplomatic proximity, as measured by sScore, should not be interpreted independently from partner-country economic capacity, trade links and broader investment potential. The simulation does not identify an optimal level of diplomatic alignment and is not used as evidence that strategic neutrality is universally more favourable for investment.

As an additional robustness check, we estimate a two-step System GMM model. This specification accounts for the dynamic structure of FDI inflows by including the lagged dependent variable and helps address potential endogeneity between diplomatic proximity and investment flows. In line with the revised theoretical framework, the squared term of diplomatic proximity is included as an exploratory extension to examine whether the relationship departs from strict linearity.

The estimation results, presented in Table 5, show that the lagged FDI coefficient is positive but not statistically significant, indicating limited evidence of persistence in FDI inflows. The linear term of bilateral diplomatic proximity remains negative and marginally significant, while the squared term is positive and also marginally significant. These results are consistent with the central *friendship paradox*, as they confirm that stronger diplomatic proximity is not associated with higher FDI inflows in the Serbian case. However, the quadratic term is interpreted cautiously and remains secondary to the main finding. The GMM specification therefore does not shift the central conclusion toward an inverted-U argument; rather, it provides an exploratory indication that the diplomacy-FDI relationship may contain some non-linear elements, while the main contribution of the paper remains the negative association between diplomatic proximity and FDI.

Table 5: Two-step System GMM model results

Variable	Coefficient	Std. Error	z	p-value
L.FDI	0.0751	0.1110	0.68	0.499
Bilateral_Diplomatic_Relations	-141.3936	76.6808	-1.84	0.065
Bilateral_Diplomatic_Relations^2	134.5058	70.6452	1.90	0.057
lnGDP_Srb	-6.6334	4.3578	-1.52	0.128
lnGDP_partner_country	4.7386	3.6189	1.31	0.190
distance	-0.0081	0.0060	-1.36	0.174
lnExport	-0.5119	1.0239	-0.50	0.617
Globalisation index	0.6056	0.4816	1.26	0.209
GDPgrowth	0.1762	0.1642	1.07	0.283
InflationRate	0.0727	0.1719	0.42	0.672
Taxes	0.2007	0.1202	1.67	0.095
EU_member_state	-26.9213	2.8618	-9.41	0.000
common_border	5.4288	17.4701	0.31	0.756

Note: Diagnostics: Observations: 400; Groups: 50; Instruments: 35; AR(1) p-value: 0.003; AR(2) p-value: 0.879; Hansen test p-value: 0.276; Sargan test p-value: 0.275

Source: Authors' calculations

Among the control variables, most coefficients retain the expected signs, although their statistical significance is reduced in the dynamic specification. This is not uncommon in System GMM estimation, where the inclusion of instruments and the correction for endogeneity may increase standard errors (Windmeijer, 2005). GDP growth and the globalisation index remain positively signed, but do not reach conventional significance levels. Similarly, the statistical insignificance of inflation and taxes should not be interpreted as evidence that these factors are irrelevant for investors, but rather as an indication that their independent effect is not isolated in this specific bilateral specification once other macroeconomic, bilateral and partner-country controls are included. One notable result is the coefficient for EU membership, which is statistically significant and negative in the dynamic specification. Although this result differs from the static models, it should be interpreted cautiously. It may suggest that formal regional or institutional proximity does not automatically translate into higher FDI inflows when other factors, such as partner-country investment capacity, sectoral strategies, trade links and diplomatic positioning, are also taken into account. This interpretation is consistent with earlier research showing that integration into supranational frameworks does not necessarily increase investment attractiveness in all country contexts (Elkomy et al., 2016).

The dynamic specification is therefore used primarily as a robustness and exploratory check. It is consistent with the central finding that stronger diplomatic proximity is not associated with higher FDI inflows in the Serbian case. The negative coefficient of diplomatic proximity remains the key result, while the positive and marginally significant squared term suggests only that the relationship may contain some non-linear elements. This evidence is not strong enough to make the inverted-U relationship or strategic neutrality the central conclusion of the paper. Instead, it supports the main *friendship paradox* argument: diplomatic closeness alone is not sufficient to attract investment when politically close partners lack strong outward investment capacity.

At the same time, these findings do not imply that diplomacy is irrelevant for FDI. Rather, they refine the expected role of diplomacy in investment attraction. Previous studies have shown that political alignment and diplomatic activity can support bilateral trade, investment flows and broader economic cooperation (Fernandes & Forte, 2022; Musera, 2020; Peternel & Grešš, 2021; Škare et al., 2020). However, the Serbian case suggests that diplomatic proximity is more likely to support investment when it is accompanied by economic fundamentals, trade intensity, partner-country capital capacity and credible investment opportunities. This is also consistent with research indicating that the economic effects of diplomatic activity may be particularly relevant for developing and transition economies (Creusen & Lejour, 2011).

The implication is therefore analytical rather than prescriptive. The results suggest that FDI inflows should be understood as the outcome of interaction between diplomatic proximity, partner-country economic capacity and Serbia's specific geopolitical position. In this sense, diplomatic flexibility and economically oriented engagement remain relevant, but the results do not provide a basis for recommending a single optimal level of diplomatic alignment or for treating strategic neutrality as the central policy conclusion of the paper.

6. Conclusion

This study examined the relationship between bilateral diplomatic proximity and FDI inflows in Serbia by extending the gravity model with a political and geopolitical dimension. The initial hypothesis (H_1), which proposed that stronger bilateral diplomatic proximity between Serbia and FDI-origin countries would be positively associated with FDI inflows, is not supported by the empirical results. Instead, the findings support H_2 and reveal a *friendship paradox*: in the Serbian case, higher diplomatic proximity is associated with lower FDI inflows.

This finding represents the central contribution of the paper. It shows that diplomatic closeness does not necessarily translate into investment attraction, particularly when politically close partners have limited outward investment capacity. In Serbia's case, several countries with high diplomatic proximity are neighbouring or politically aligned economies with relatively limited capital-exporting capacity. Conversely, several countries with lower diplomatic proximity are economically larger, more globally integrated or more active as outward investors. The results therefore indicate a mismatch between political closeness and investment capacity, suggesting that diplomatic proximity should be analysed together with economic fundamentals, trade relations, market strategies and partner-country capital capacity. The paper also contributes to the gravity-based literature by showing that political and diplomatic variables may alter, rather than simply reinforce, conventional expectations about investment flows.

The study has several limitations. First, the analysis is restricted by the availability of sScore data, which ends in 2018. This means that more recent geopolitical changes can be discussed only as contextual background and are not directly included in the econometric models. Second, sScore captures foreign-policy similarity and broader geopolitical alignment, but it does not directly measure investor perceptions, institutional trust, regulatory quality, political stability, informal diplomatic channels or sector-specific diplomatic engagement. Third, the study focuses on Serbia as a single host country with a specific geopolitical and economic position. The findings should therefore be interpreted as country-specific evidence rather than as a general model of the diplomacy-FDI relationship across all economies. Finally, although the empirical strategy includes fixed effects and a dynamic GMM specification, the results should be understood as evidence of conditional associations rather than definitive causal effects.

Future research could extend this analysis in several directions. Comparative studies across other transition and small open economies, including both EU and non-EU cases, would help assess whether the *friendship paradox* is specific to Serbia or whether it also appears in other geopolitically positioned countries. Future studies should also update the analysis when newer diplomatic proximity data become available or use alternative indicators capable of capturing diplomatic relations during the crisis periods of the 2020s. Future work could also use sector-level FDI data to examine whether diplomatic proximity matters differently across industries, particularly in infrastructure, energy, technology or manufacturing. Finally, qualitative diplomatic indicators and investor perception surveys could provide a deeper understanding of how political signals, geopolitical alignment and diplomatic relations are interpreted by foreign investors.

The implication is analytical rather than prescriptive. For small and transition economies, diplomatic engagement may be most relevant when it is connected to economic fundamentals, credible investment opportunities and partner-country capital capacity.

From a policy perspective, this suggests that investment-promotion efforts should account for partner-country investment capacity and the diversification of FDI sources, rather than rely on political or diplomatic closeness alone. For Serbia in particular, this implies that economic diplomacy is likely to be most effective when it targets partners with genuine capital-exporting potential, while preserving flexibility across both EU and non-EU sources of investment.

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Paradoks prijateljstva u investiranju: Kako diplomatska bliskost utječe na priljev izravnih stranih ulaganja

Nevena Veselinović[1], *Filip Ž. Bugarčić*[2]

Sažetak

Ova studija ispituje je li bilateralna diplomatska bliskost između Srbije i zemalja porijekla stranih izravnih ulaganja (FDI) pozitivno ili negativno povezana s priljevima stranih izravnih ulaganja. Koristeći prošireni gravitacijski model i dinamičku panel-specifikaciju (System GMM), uvodi se indeks političke bliskosti (sScore) koji obuhvaća sličnost vanjske politike i geopolitičko usklađivanje, uz standardne ekonomske determinante. Kvadratni član uključen je kao eksplorativna provjera nelinearnosti. Statički modeli pokazuju statistički značajnu negativnu povezanost između diplomatske bliskosti i FDI-ja, koja ostaje negativna, ali samo granično značajna u dinamičkoj specifikaciji. Srbija stoga privlači više ulaganja iz zemalja koje nisu njezini najbliži diplomatski partneri, što se u radu naziva „paradoksom prijateljstva“. Simulacija javnih politika ilustrira veličinu ove povezanosti, dok se dokazi o nelinearnosti smatraju sekundarnima. Rezultati upućuju na to da su ekonomski fundamenti i investicijski kapacitet zemalja partnera važniji za FDI od diplomatske bliskosti, budući da su najbliži partneri Srbije u većini slučajeva gospodarstva s ograničenim kapitalnim kapacitetima. Analiza pokazuje da diplomatsku bliskost treba razmatrati zajedno s ekonomskim fundamentima i kapitalnim kapacitetom zemalja partnera, umjesto da se unaprijed pretpostavlja kako ona sama po sebi povećava ulaganja. Ovi su rezultati specifični za promatranu zemlju te ih treba tumačiti kao uvjetovane povezanosti, a ne kao uzročno-posljedične učinke.

Ključne riječi: *izravna strana ulaganja, diplomatski odnosi, politička bliskost, gravitacijski model, GMM, Srbija*

JEL klasifikacija: *F21, F59, C33, O52*

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Book reviews, reviews on doctoral dissertations, as well as reviews on international conferences and seminars are not submitted to extramural reviews. They are accepted or rejected by the Editor and co-editors.

Review process

All scientific articles submitted for publication in *Zbornik radova Ekonomskog fakulteta u Rijeci: časopis za ekonomsku teoriju i praksu/Proceedings of Rijeka Faculty of Economics: Journal of Economics and Business* are double-blind peer review by two academics appointed by the Editorial board: one from Croatia and one from abroad. Reviewers stay anonymous for the authors and so do the authors for the reviewers. The reviewers are asked to apply highest international standards in their assessment of the submitted work. Reviewers receive an article and a *Reviewer Evaluation Form* with instructions how to fill it in. If the article does not fulfill the primary criteria of originality and relevance to the subject, it should not be accepted.

The categories in which articles, if judged positively, might be classified are:

Original scientific paper is a scientific paper that includes new results based on the research. The information given in the article can be verified by:

a) reproducing methodological procedure and obtain the same/similar results or with tolerable degree of mistakes as estimated by the author himself, or
b) repeating the author's observations and judge his analyses, or
c) checking the author's analyses and deduction on which the author's analyses are based.

Preliminary communication is an article that includes at least one or more pieces of scientific information, but does not include the necessary details to check the scientific cognition.

Conference paper is an article that deals with the author's presentation at a conference, and has not been previously published as a full text.

Review article is an article that analyses a special scientific problem already dealt with in published scientific works, but his approach is original and new.

Professional paper is an article that deals with specific problems in some professional areas.

After receiving the reviews, the Editorial Board will give clear general instructions to the author for further work on the manuscript. The comments and suggestions made by the reviewers should be addressed and closely followed by the author prior to final recommendation on acceptance or rejection made by the Editorial Board.

Only manuscripts with two positive reviews are published.

After completion of peer review and amendment of the text of the accepted articles by the authors and editors, Editor-in-Chief, proposes the sequence of accepted papers in the table of contents.

Criteria for the order are:

(1) categorization according to the degree of scientific excellence,
(2) in case of two different levels of categorization of a particular article by reviewers, Editor-in-Chief proposes a decision to the Editorial Board, and as a rule, in favour of the author, i.e. a higher category,

(3) appreciation of topical issues, authors and common interest of the Journal taking into account the competitiveness at the same level of scientific excellence (category).

To increase the quality and number of papers published, the Editorial Board strives to fasten the publishing process by informing the authors on the status of their articles within ten working days of the submission. Provisional deadline for finishing the reviewing process, technical revisions, and online publication of the paper shall last no longer than two months. Moreover, as of 2018, the forthcoming articles, included within the regular biannual issues, are initially published on our Journal's website.

Besides the traditional focus on empirical papers, the Journal invites authors to submit theoretical papers which should cover the gap of lack of more fundamental research and meta-analysis of literature aiming at providing the basis for more sound empirical research as well as advancements of new ideas and insights in economic theory and practice. We particularly welcome papers which are theoretically well-based (but for most people understandable) papers with clear policy- and future-oriented analysis/messages/recommendations; research focusing on the interdependence of various, particularly current, economic developments; studies focusing on the transdisciplinary and interdisciplinary character of economic analyses (technical, legal, social, economic and other fields).

The journal draws methodology for theoretical papers from the Journal of Economic Perspectives (https://www.aeaweb.org/journals/jep), with similar goals: to synthesize and integrate lessons learned from the most relevant fields and dilemmas of contemporary economic theory and practice; to provide the economic analysis of public policy issues; to encourage cross-fertilization of ideas among the scientific areas of thinking; to offer readers an accessible source for state-of-the-art economic thoughts and to suggest directions for future research. The focus of theoretical articles should be on understanding the central economic ideas of a question, what is fundamentally at issue, why the question particularly important, what the latest advances are, and what facets remain to be examined.

In case of submission of theoretical paper instead of section *Empirical data and analysis*, authors should include the one on *Theoretical/conceptual analysis,* where the authors should provide argumentation based on their proposed methodology/ concept of research. In this section, authors should provide a novel analysis of the field/topic, provide theoretical argumentation, which proves their hypothesis by using different available tools such as mathematical, graphical, or any other that present and reveal economic relationships in regards to the specific scientific area.

Organization of the manuscript

The manuscript should include the research aim and tasks, with detailed methodology, the research objective, achieved results and findings, conclusions and a list of references.

The authors of the manuscript should conform to the format and documentation requirements that are given below:

The separate page should contain: the article title, the author's full name, academic affiliation (title, institution, scientific field) and e-mail address. If there are more authors than one, full names, respective affiliations and addresses of co-authors should be clearly stated. Authors'academic affiliation should be:

– in the language of the article,
– in Croatian language,
– in English if the original language of the article is other than English.

The first page should contain: the article title, abstract, JEL classification and key words in the language of the article. At the end of the article all data should be also:

– in Croatian language,
– in English if the original language of the article is other than English.

Main body of the text should contain: introduction, headings, footnotes, references in the text, tables, figures, conclusions and references.

Technical requirements

The manuscript submitted for publication should be in Microsoft Office Word (Ver. 95+), with maximum length up to **8,000** words in length (16-20 A4 size pages), printed in font style Times New Roman (12 point), single-spaced, justified and without any special styling. Should a word, a phrase or a sentence be highlighted, <u>italic font style can be used and never bold</u>. Paragraphs are divided by double spacing and all margins are at 2.5 cm. In case the paper exceeds the normal length, the Editors' consent for its publication is needed.

JEL classification should be suggested by the authors themselves according to the classification available on the Journal of Economic Literature website: http://www.aeaweb.org/journal/jel_class_system.html.

Footnotes could be used only as an additional explanatory section of the text and should be numbered consecutively in Arabic numerals.

Section headings (from Introduction to Conclusions) must be short, clearly defined and bear Arabic numerals. If there are subsection headings they are outline numbered (e.g. 1; 1.1.; 2.; 2.1.; 2.1.1. etc.)

All *tables and figures* should bear Arabic numerals and must have captions. Tables set in MS Word may be included in the text.

Note: If MS Excel or other programs are used for tables, figures or illustrations, make sure to enclose them as a separate file on disk, separately from the text.

Before submission of the manuscript, the authors of the manuscript are advised to conform to the format and documentation requirements.

Text organization and style

Authors should apply scientific methodology in presenting the contents of their papers complying with the standards of scientific publications ("Harvard style"). This implies the procedure as follows:

(1) Title and the content of the paper:

The title is the most important summary of a scientific article, which reflects the scope of investigation and the type of study. Therefore, the title should not contain words such as “analysis”, “methods” and similar.

The content of the paper consists of:

- *Abstract* – below the title
- *Key words*
- *JEL classification.*

It is followed by the main body of the paper divided into sections. The section headings are as follows:

- *Introduction*
- *Literature review*
- *Methodology/method/model/conception of analysis* (the third section)
- *Empirical data (documentation background) and analysis* (the fourth section)
- *Results and discussion* (the fifth section)
- *Conclusions* (the sixth section).

(2) The content of some parts of the material presented:

a. **Abstract** – up to 100-250 words must contain:
   - purpose and research objective,
   - methodology/method/model/conception of analysis,
   - main findings and results of research (analysis),
   - the underlined conclusion of research.

   The abstract should not be written in paragraphs!

b. **Key words** should disclose the essence of the article (up to 5 key words).

c. **JEL classification** – the author should classify the subject matter of the article according to the code of The Journal of Economic Literature (JEL).

d. **Introduction** – defines the problem and the subject matter of the research referring to recent bibliography and findings. However, these can more specifically be dealt with in the second section *Literature review*. The last part of the introduction is reserved for setting the hypothesis of the research that will be later on analyzed at the beginning of the conclusions. Finally, Introduction ends up by giving clues of the organization of the text.

e. **Literature review** – precedes a research section providing readers with a cutting-edge context of the referential literature dealing with crucial points of current knowledge based on the relevant results of the current research. Literature review should be a synthesis of previous research, justifying the theoretical and empirical contributions of the respective paper, a not a simple listing of previous scientific contributions.

- **f. Methodology/method/model/conception of analysis** – usually in the third section of the paper, methodology/method/model/conception of the analysis should be transparently presented and pointed out in case of the research results being subjected to re-testing by interested researchers (it is one of the fundamental principles of the scientific methodology).
- **g. Empirical data and analysis –** contain documentation background and the results of the empirical analysis. The data sample shall be elaborated and the obtained results shall be explained based on statistical and econometric features, and their economic meaning.
- **h. Results and discussion –** explain the results, especially their economic significance and messages. In this section, the author(s) need to elaborate how their results and conclusions contribute to the scientific field and provide practical implications and recommendations.
- **i. Conclusions –** is not supposed to be a summary! Conclusions are the author's original thoughts and evaluation of the obtained results including the items as follows:
- **j.** Explanation of the working hypothesis – proved or not proved.
- **k.** Assessment of the results of research/analysis with the focus on what can be classified as a new contribution to economic science.
- **l.** Attention drawn to research limitations and problems.
- **m.** Guidelines to future research.
- **n.** Assessment of institutional-systemic implications of the results obtained by the research (suggestions and recommendations for direction or changes of economic system, economic and financial policy, development policy, instruments, measurements or similar).

  It is recommended not to write conclusion in paragraphs.

(3) References should include only the titles (sources) that have been referred to and quoted in the paper.

TABLES should be included in the text in order to present the exact values of the data that cannot be summarized in a few sentences in the text. Each column heading for numerical data should include the unit of measurement applied to all data under the heading. Large numbers can be expressed in smaller units with appropriate column headings (in thousands, millions, etc), and logical presentation of data using table grid option in MS Word for table lines (both vertical and horizontal). Each table should be self-explanatory, bearing Arabic numerals (e.g. Table 1, Table 2, etc.) with an adequate title (clearly suggesting the contents) and the source of the data should be stated below the table, if other than author's.

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Note. The text should not simply repeat the data contained in tables and figures, i.e. the text and the data in tables and figures should be related in the text by means of reference marks.

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All references in the text should be cited **as originally given**, i.e., forms such as *"Ibid."*, *"Op. cit."*, and the like are **not used**. Sources should be cited **in the text**, not in footnotes. If there are multiple works by the same author published in the same year, **"a, b, c"** should be added after the year. The in-text citation should be placed in parentheses, containing the author's surname and the year of publication.

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Article in a journal

Author Surname, Initials. & Surname, Initials. (Year). Title of the article. *Title of the journal in italics*, Volume number (Issue number), Page range (If the journal article has an article number instead of a page range, include the word "Article" and then the article number instead of the page range.). DOI

See example:

Brmalj, N., Olgić Draženović, B., & Bogdan, S. (2025). Unlocking the pension fund performance: A systematic literature review approach. *Zbornik radova Ekonomskog Fakulteta u Rijeci – Proceedings of Rijeka Faculty of Economics*, 43(1), 33–62. https://doi.org/10.18045/zbefri.2025.1.8

Parenthetical citation: (Brmalj et al., 2025)

Narrative citation: Brmalj et al. (2025)

Hoepner, A. G. F., & Schopohl, L. (2020). State pension funds and corporate social responsibility: Do beneficiaries' political values influence funds' investment decisions? *Journal of Business Ethics*, 165(3), 489–516. https://doi.org/10.1007/s10551-018-4091-z

Parenthetical citation: (Hoepner & Schopohl, 2000)

Narrative citation: Hoepner and Schopohl (2020)

Book

Author Surname, Initials. (Year). *Title of the book in italics*,. Publisher of the book. (If the book includes a DOI, include the DOI in the reference after the publisher name.)

See example:

Rupčić, N. (2024). *Managing learning enterprises: Challenges, controversies and opportunities* (Vol. 14). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-57704-8

Parenthetical citation: (Rupčić, 2024)

Narrative citation: Rupčić (2024)

Published conference paper:

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Matić, R., Šegota, A., & Blažić Pečarić, H. (2025). Is Primorje-Gorski Kotar County efficient in fiscal terms? In S. Drezgić, V. Buterin, N. Dukić Samaržija, A. Arbula Blecich, & B. Fajdetić (Eds.), *Artificial intelligence and productivity: Challenges and opportunities* (pp. 48–69). University of Rijeka, Faculty of Economics and Business.

Ntoyanto-Tyatyantsi, N., & Amadi-Echendu, A. (2025). Circular economy technology management practices in agri-value chains using the natural resource-based view. In R. Zimmermann, J. C. Rodrigues, A. Simoes, & G. Dalmarco (Eds.), *Human-centred technology management for a sustainable future* (pp. 1–11). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-72494-7_1

Additional examples and reference types can be found at: https://apastyle.apa.org/style-grammar-guidelines/references/examples

Editors recommend that references be prepared using a bibliography software package, e.g., the free, quick-reference tool **ZoteroBib** (https://zbib.org/).

Other important notes

If the author of the manuscript does not conform to the primary format and documentation requirements that are given in the instructions, editors reserve the right to reject the article, or adapt it to comply with the Journal standards, providing other acceptance criteria are fulfilled.

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