Comparative Economic Research

Central and Eastern Europe

Volume 29 No. 1/2026

WYDAWNICTWO UNIWERSYTETU ŁÓDZKIEGO

WYDZIAŁ EKONOMICZNO-SOCJOLOGICZNY Uniwersytet Łódzki

COPE Member since 2018 JM13708

Institute of Economics • University of Lodz

Comparative Economic Research

Central and Eastern Europe

Volume 29 No. 1/2026

WYDAWNICTWO UNIWERSYTETU ŁÓDZKIEGO
Łódź 2026

WYDZIAŁ EKONOMICZNO-SOCJOLOGICZNY
Uniwersytet Łódzki

COPE
Member since 2018
JM13708

INITIATING EDITOR
Sylwia Mosińska

TECHNICAL EDITOR
Mateusz Poradecki

COVER DESIGN
Katarzyna Turkowska
efectoro.pl agencja komunikacji marketingowej

Printed directly from camera-ready materials provided to the Lodz University Press

Journal affiliated with the Faculty of Economics and Sociology of the University of Lodz

Published by Lodz University Press
First Edition. W.12055.26.0.C
Printing sheets 23.5

ISSN 1508-2008
e-ISSN 2082-6737

Lodz University Press
90-237 Łódź, 34A Matejki St.
www.wydawnictwo.uni.lodz.pl
e-mail: ksiegarnia@uni.lodz.pl
tel. +48 42 635 55 77

BOARD OF MANAGING EDITORS

Contents

In Memoriam

Zofia Wysokińska

(1949–2026)

Professor Zofia Wysokińska, PhD – Founder and Editor-in-Chief of *Comparative Economic Research – Central and Eastern Europe* journal – passed away on February 10, 2026. Her concept of establishing an international scientific journal dedicated to the comparative aspects of systemic transformation processes in Central and Eastern European countries emerged in the 1990s. The first issue of the journal was published in 1998. From that time onward, Professor Wysokińska pursued, with unwavering dedication, the goal of ensuring the journal's high academic standards and shaping it into a platform for substantive dialogue on key economic challenges in the region. As the journal developed, its comparative scope was broadened to include economic processes taking place in other parts of the global economy. Professor Wysokińska served as Editor-in-Chief until 2024, subsequently assuming the role of Honorary Editor-in-Chief.

Professor Wysokińska was affiliated with the Institute of Economics at the University of Lodz from 1976. Her scientific work focused on international economics, in particular international trade, European integration, sustainable development, and the circular economy. She headed the Department of World Economy and European Integration at the Faculty of Economics and Sociology from 1999 to 2019. She also served as Vice-Dean for Research at the Faculty of Economics and Sociology (2002–2007) and as Vice-Rector for International Relations

at the University of Lodz for two terms (2009–2016). Her remarkable professional activity encompassed scientific research, teaching, and academic administration.

Professor Wysokińska was the author of more than 250 publications, including 15 monographs, among them two major single–authored works: *Dynamiczne współzależności wymiany handlowej w świetle teorii integracji i wymiany Międzynarodowej* [*Dynamic Interdependencies of Trade in the Light of Theories of Integration and International Trade*] (1995, University of Lodz Press – the book was granted the Award of the Minister of Science and Higher Education), and *Konkurencyjność w międzynarodowym i globalnym handlu technologiami* [*Competitiveness in International and Global Trade in Technologies*] (2001, PWN – the book was granted the Award of the Rector of the University of Lodz).

Since 2001, she was the Jean Monnet Professor. The title was granted based on two successful applications for European Union projects: *Jean Monnet Chair* and *Jean Monnet European Centre of Excellence*. She regularly presented her research at prestigious international conferences organised by the International Trade and Finance Association (IT&FA). She was a member of its Board of Directors and served as President of the Association in 2008.

Professor Wysokińska was also a scholarship holder of the Friedrich Ebert Foundation (Universities of Cologne and Munich), the European Commission's *Action for Cooperation in the Field of Economics (ACE)* Programme, the UK Government's *Know How Fund* Programme (University of Cambridge), and the *European University Institute* scholarship programme in Florence.

In recognition of her academic and organisational achievements, she received numerous distinctions, including the Honorary *Etoile Civique* Medal for her contribution to the development of European cooperation (Paris, 2002), the Knight's Cross of the Order of Polonia Restituta (2009), and the Medal for Long Service on the occasion of the 70th anniversary of the University of Lodz (2015).

Honour her memory!

Comparative Economic Research. Central and Eastern Europe
Volume 29 Number 1, 2026
https://doi.org/10.18778/1508-2008.29.01

Do Exchange-Rate Fluctuations Have Asymmetric Impacts on Visegrad–German Sectoral Trade?

Izabela Pruchnicka-Grabias https://orcid.org/0000-0002-7385-6286
Ph.D., Associate Professor – corresponding author, Warsaw School of Economics, Collegium of Socio-Economics, Warsaw, Poland, e-mail: ipruch@sgh.waw.pl

Scott W. Hegerty https://orcid.org/0000-0002-0999-561X
Ph.D., Professor, Northeastern Illinois University, Department of Economics, Chicago, USA, e-mail: S-Hegerty@neiu.edu

Abstract

Understanding the determinants of trade flows between countries is of particular interest to policymakers, central bankers, business owners and investors. The study examines the long-run impact of the real exchange rate, exchange-rate volatility, and output on the trade balances of 10 SITC (Standard International Trade Classification) sectors between three Visegrad countries and Germany. Because the linear Autoregressive Distributed Lag (ARDL) approach shows little effect across countries and sectors, we decompose the impacts into positive and negative changes via the Nonlinear ARDL approach. The paper adds value in the following respects. The first is that while the overall macroeconomic determinants have a relatively weak connection to these trade balances, the strongest connections are in the primary-product-producing sectors. The second finding is that while most of these trade flows often depend on the country, the sector analyzed, and the method used, there are interesting, stylized results, including the region's chemical sector and manufacturing in Hungary, for example. The third finding is that nonlinear models show cointegration between the real exchange rate and the trade balance in Visegrad-Germany trade for a higher number of industries, even though the long-run coefficients continue to be insignificant in many cases.

Keywords: trade balances, Visegrad, exchange-rate volatility, asymmetric effects
JEL: F14, F41

Funding information: Polish National Agency for Academic Exchange under the Strategic Partnerships programme, grant number BPI/PST/2021/1/00069/U/00001.
The percentage share of the Authors in the preparation of the work is: I.P.-G. – 95.00%, S.W.H. – 5.00%.
Declaration regarding the use of GAI tools: Not used.
Conflicts of interests: None.
Ethical considerations: The Authors assure of no violations of publication ethics and take full responsibility for the content of the publication.
Received: 13.03.2025. Verified: 27.03.2025. Accepted: 3.12.2025

Introduction

Understanding the determinants of trade flows between countries is of particular interest to policymakers, central bankers, business owners and investors. Since the abolition of the Bretton-Woods system, the economic literature has examined the influence of exchange rates on exports and imports. The economic theory indicates that there is a long-run relationship between exchange rates and bilateral trade. According to the Marshall-Lerner condition, depreciation of the foreign currency improves the trade balance if import-export elasticities are higher than one (Davidson 2009:125). This happens because the rise of domestic currency decreases the relative prices of foreign goods, which increases imports in the long run. In the case of depreciation of the domestic currency, the opposite effect appears. The nexus was confirmed by Bahmani-Oskooee (1991) and has been explained by Bahmani-Oskooee, Hegerty, and Harvey (2013).

Similarly, but using a different mechanism, this relationship was shown by Alexander (1952:265), who argued that devaluation influences the trade balance in two ways. First, it alters the production of goods and services, which in turn influences national income and, consequently, the absorption of goods and services. This change in absorption impacts the trade balance. Second, devaluation directly affects the absorption of goods and services, which also influences the trade balance.

On the other hand, Mundell (1963:477) looked at the problem from a monetaristic perspective, explaining that expansive monetary policy increases the money supply, leading to outflows and currency depreciation. This improves exports and deteriorates imports. Mundell (1971: 7–12) showed it in the context of the American deficit, suggesting the same mechanism.

Apart from the impact of the exchange rate on the trade balance, some papers demonstrate the influence of exchange rate volatility. Clark (1973) used the example of a single firm to show a negative nexus between exchange rate volatility and trade. He assumed that the exporter operates under perfect competition, has limited options to hedge strategies, and is risk-averse (preferring fixed profits over time). Clark showed that when exchange rates fluctuate and are uncertain, the exporter is uncertain about its income calculated in domestic currency. Thus, when the exchange rate increases, it is likely to reduce output and exports to avoid unexpected losses caused by an unfavorable foreign exchange rate.

In the years that followed, up to the early 1990s, other publications also identified a negative relationship between exchange rate volatility and trade (Hooper and Kohlhagen 1978; Giovannini 1988). An important similarity between these papers is that they are based on strict assumptions. However, when other authors relaxed those assumptions, the relationship was found to be less clear-cut (Auboin and Ruta 2013). Additionally, the relationship is influenced by the rapid development of financial derivatives, which enabled currency risk hedging strategies. Because of these increasingly complex mechanisms, the conclusions drawn from more recent research are often contradictory (Jiang and Liu 2023).

Analyses have expanded to examine trade at a disaggregated level – including sector- or industry-level data – using various cointegration methods that distinguish between short-run and long-run processes (Kashi and Lynn 2012; Muteba and Dube 2014; Pruchnicka-Grabias,

Piekunko-Mantiuk, and Hegerty 2024). A relatively new innovation has been the application of nonlinear methods to further separate the effects of positive and negative changes in explanatory variables. Studies have demonstrated that currency appreciations and depreciations can have asymmetric effects (Bahmani-Oskooee and Harvey 2021a; Xu, Bahmani-Oskooee, and Karamelikli 2021).

This study extends the literature by focusing on an important set of partnerships in Central Europe: the trade relationships between Germany and the floating-currency economies of Czechia, Hungary, and Poland (three of the four Visegrad countries). The fourth Visegrad country, Slovakia, uses the euro. Large amounts of agricultural and manufacturing trade move between each pair every day. Here, we examine the period from 2004 to 2023 using monthly data.

The history of trade between Germany and these three Visegrad countries (V3)1 dates back to the 1990s, when the German–Central European supply chain developed. As a result, Germany and the V3 quickly increased their bilateral trade, which grew more rapidly than for other CEE countries (International Monetary Fund 2013: 1, 3). According to Eurostat data and our own calculations, total exports between Germany and V3 amounted to €4.3 billion, while in 2013, this figure had nearly doubled to €7.3 billion, and by 2023, it again doubled to €14.5 billion. Imports followed a similar trajectory. In 2004, the figure was €3.3 billion, by 2013, it had more than doubled to €7.5 billion, and in 2023, it had more than doubled again to € 17.5 billion. Over 20 years, this represents a 335% rise in exports and a 537% increase in imports. Such a tremendous increase warrants a separate analysis of its determinants.

Given these trends, the paper examines the long-term impact of the real exchange rate, output, and exchange-rate volatility on trade balances between the V3 and Germany.

Since the variables under consideration have little effect across countries and sectors, it is worthwhile decomposing the exchange rate into positive and negative changes via the Nonlinear ARDL approach of Shin, Yu, and Greenwood-Nimmo (2014). It helps show the difference between the influence of positive and negative changes in the examined variables. Following Bahmani-Oskooee, Harvey, and Hegerty (2017), who analyzed Japanese trade with twelve partners, we apply both linear and nonlinear models for V3-Germany trade. Our findings indicate no clear pattern in trade flows across industries or countries and that more industries are cointegrated with the real exchange rate and industrial production using the nonlinear method. The key focus here is the disaggregated exchange-rate variables, which clearly show asymmetric effects. Exchange-rate volatility, as expected based on previous studies such as McKenzie (1999) and Bahmani-Oskooee and Hegerty (2007), has an ambiguous effect on trade balances.

Using nonlinear models helps monitor complex relationships that linear models – which consider only the simplest connections – cannot detect. Specifically, since currency appreciations might hurt a country's exports more than depreciations help them, decomposing the real exchange rate into its positive and negative changes can also reveal this asymmetry. The opposite may also be true, and this asymmetry can similarly affect imports. Additionally, if positive

1 For the purposes of this article, we refer to these countries as the V3, although historically, the V3 referred to the unified country of Czechoslovakia along with Hungary and Poland.

and negative changes have significant results that are opposite in sign, their combined impact might lead to an insignificant aggregated variable. Comparing the results of the nonlinear model to those of the aggregate model will help explore these differences.

The paper extends the existing literature by analyzing the V3 countries' trade balances with Germany for 10 SITC (Standard International Trade Classification) sectors. This topic has not yet been discussed in the literature in this context. This paper offers a novel perspective by showing differences between different sectors and their sensitivity to changes in the real exchange rate and its volatility, as well as to domestic and foreign industrial production.

The paper is structured as follows. Section 2 provides a literature overview. Section 3 describes the methodology used. Section 4 presents the results. Section 5 concludes.

Literature review

Previous studies have examined the influence of the exchange rate and other macroeconomic variables on the trade balance, but there has been no such analysis for the Visegrad countries and their partners. In this paper, we conduct such an analysis with regard to ten different SITC sectors. Furthermore, while much of the literature concentrates on the symmetric influence of appreciations and depreciations on the trade balance, we also consider asymmetrical relations using nonlinear models. This methodological approach allows us to demonstrate differences in how the trade balance reacts to changes in key variables. In this strand of the literature, papers commonly include output (often proxied by industrial production), the exchange rate, and often exchange rate volatility. Some authors focus on the impact of two or three of these factors. Below, we summarize the most important papers in this field, grouping them according to the scope of their analysis.

Conclusions on the role of exchange rate fluctuations on the trade balance vary significantly. They depend on the periods analyzed, the country, the trade sector, and the methodology – including the time span and the model used. Some papers show that a relationship exists, while others find none for some countries or sectors.

For instance, Bahmani-Oskooee and Cheema (2009) analyzed the trade balance of Pakistan with 13 trading partners and found a long-run link between the exchange rate and the trade balance for half of the countries examined. They used cointegration methods, including bounds-testing (ARDL) and Johansen approaches. Šimáková (2016) studied long-term relationships between exchange rates and trade in the Visegrad countries from 1999 to 2014 but used a simpler version of the trade balance model created by Rose and Yellen (1989). Šimáková revealed that connectedness depends on countries and product groups. Jiang and Liu (2023) analyzed relationships between China and their major trading partners, showing different conclusions for USD in China–US trade and EUR in China–Japan trade. In the former case, the currency depreciation improves the trade balance, while in the latter, it worsens it. Geldner (2024) analyzed the influence of the exchange rate on the trade balance between G10 and BRICS countries, applying quantile regression. He found that the relationship varies depending on whether the economy

is advanced or emerging, likely due to differences in the goods that are exported and imported by these two groups of countries, so their liability to the exchange rate is non-identical.

Some recent studies considered differences in relations when the exchange rate rises or decreases. Some showed different conclusions for exchange rate appreciation and depreciation, while others found that the result depends on the method used and the countries and sectors analyzed.

For example, Bao et al. (2023) studied the links between the American dollar and the trade balance between the EU countries and India. They used the NARDL model to demonstrate that while India's currency depreciation does not increase trade, appreciation decreases it. Similarly, Wang (2023) noted that the depreciation of the Chinese currency does not have a significant impact on US trade. This is contrary to other papers (Barkat, Jarallah, and Alsamara 2023), which reported that the response to depreciation is stronger than to appreciation. Ren and Sakouba (2024) confirmed a long-term relationship between the exchange rate and trade balance between China and East African countries, regardless of whether the exchange rate appreciates, depreciates, or is devalued.

Some papers analyze the influence of exchange rates on the trade balance by focusing on individual countries or bilateral trade relationships. A key strength of our paper is that we examine a group of countries and sectors, allowing us to highlight differences between them. Omer, Kamal, and Haan (2023) analyzed the influence of exchange rates on Pakistan's imports and exports with the GMM estimator for the period from 1968 to 2019 and found that currency depreciation boosts exports and reduces imports. Siddique, Anwar, and Quddus (2020) used asymmetric ARDL methods to show the negative relationship between the exchange rate and Pakistan's exports. Wang (2023) studied the long-run asymmetric impact of the exchange rate on the trade balance between the USA and China with linear and nonlinear ARDL methods. She emphasized that while a relationship exists, it is subject to structural breaks. In contrast, we take a comprehensive approach by examining the V3 countries as a group and studying their trade with Germany.

Conclusions regarding the influence of exchange rate volatility on exports are mixed and depend on the countries and sectors analyzed. Many authors analyze aggregate exports rather than dividing them into sectors, while others concentrate on particular industry sectors. For example, Bosupeng, Naranpanawa, and Su (2024) noted that exchange rate volatility decreases the trade balance in developed countries but increases it in developed economies. Hall et al. (2010) compared the effect of exchange rate volatility on trade in emerging market economies and other developing countries, finding that open capital markets reduce the influence of volatility on exports. Šimáková and Stavarek (2015) showed that for Czechia's trade with its largest trading partners, higher exchange rate volatility increases the trade of some products, while for others, the adverse effect is observed.

Similar mixed results are observed for the impact of exchange rates on the trade balance. For instance, Muteba and Dube (2014) examined the influence of exchange rate volatility on trade between South Africa, China, and the United States, noting that the impact varies by industry

and sector. Kashi and Lynn (2012) examined the trade between the US and OECD countries. They found that the exchange rate volatility influences the agricultural sector, while the exchange rate impacts the non-agricultural sector. Bahmani-Oskooee, Hegerty, and Zhang (2014) analyzed the influence of exchange rate volatility on exports and imports across different industries in South Korea with the U.S. and showed that it can be positive, negative, or insignificant, depending on the sector.

The next group of papers relevant to this study are those that focus on the influence of industrial production on trade flows. Studies examining industrial production – itself a key control variable in the current study are not as numerous as those for exchange rate or exchange rate volatility. Moreover, most of these studies consider aggregated production rather than distinguishing between SITC sectors, though some do focus on specific sectors.

For example, Sankaran, Krishna, and Vadivel (2021) studied the relationship between industrial output in the manufacturing sector and exports in ten emerging economies, finding that output increases exports but without distinguishing between sectors. Chit, Rizov, and Willenbockel (2010) showed a negative influence of exchange rate volatility on exports in five emerging Asian economies, again without sectoral analysis.

In contrast, Ali, Muzammil, and Umar (2022) showed a positive impact of exchange rate volatility on exports in most of the developed countries they investigated (the UK, Sweden, Germany, Poland, Italy, France, Denmark, Austria, and Belgium). However, no sectors were individually analyzed. Wa Cipamba (2015) showed that GDP stimulates exports in South Africa in the long run but did not conduct a disaggregated study. Awokuse (2005) showed a significant link between economic growth and exports in South Korea, while Sharma and Dhakal (2006) showed that economic growth increases export dynamics in some developing countries. Tyler (1981) also showed the nexus between economic growth and exports. Meanwhile, Hacker and Hatemi-J (2003) concluded that both domestic and foreign production influence exports in the case of Sweden. Abolagba, Onyekwere, and Agbonkpolor (2010) showed the significant influence of the industrial production of rubber and cocoa in Nigeria for exports.

Some studies, like ours, consider exchange rate, volatility, and industrial production together. For instance, Wang and Barrett (2007) showed that industrial production, the real exchange rate, and its volatility all influence trade between US and Taiwan. Bahmani-Oskooee and Hegerty (2009) showed that exchange rate volatility significantly influences trade flows between the US and Mexico for one-third of industries in the long run. They also confirmed the influence of the real exchange rate and industrial production, using non-linear models.

In addition, many existing studies of trade relations do not focus on asymmetrical relations. For instance, Akbostanci (2004) showed that for Turkey, depreciation stimulated the trade balance in the long run between 1987 and 2000. Bahmani-Oskooee and Kutan (2009) examined the relationship between foreign exchange rates and trade balance between emerging East European countries from January 1990 to June 2005, confirming the J-curve effect for Bulgaria, Croatia, and Russia. Šimáková (2014) analyzed the relationship between Slovakia and its main partners between 1997 and 2013. She used the Johansen cointegration and VECM model to demonstrate

that the foreign rate depreciation positively influences Slovakia's trade balance in both the short and long terms. Khouiled, Chini, and Benrouina (2023) analyzed the long-term relationship between foreign exchange rates and trade balance for countries from North Africa between 1990 and 2019. They used a panel ARDL model to confirm long-term connectedness. Narayan and Smyth (2006) investigated the interdependence between the exchange rate and China's trade balance with the US, revealing that currency devaluation improves the trade balance in the long run. Puah et al. (2008) showed no long-term interdependence between exchange rates and trade balances in four out of five ASEAN countries from 1970 to 2004.

We contribute to the existing literature by extending this analysis to trade between the V3 and Germany, employing both linear and nonlinear models. The argument for incorporating non-linear models is that the literature emphasizes their ability to show new relationships that linear models may overlook. Nonlinear approaches also allow us to distinguish the effects of positive and negative changes in variables, which aligns with Bahmani-Oskooee, Harvey, and Hegerty (2017), who examined Japanese trade with twelve partners. They applied both linear and nonlinear ARDL methods and noted that the latter showed stronger relationships. The linear model showed that in the long run, Japan's trade balance with three countries improved when the yen depreciated, whereas the nonlinear model revealed this effect for seven countries.

Similarly, Bahmani-Oskooee and Harvey (2021a) demonstrated the absence of asymmetric relationships between exchange rate volatility and trade between the US and Mexico when employing linear models. Bahmani-Oskooee and Fariditavana (2016) examined US trade with its six largest partners, finding that the linear ARDL model indicated a J-curve effect for trade with three countries while the nonlinear ARDL model revealed it for five. They also noted that the impact of the exchange rate on the trade balance is mostly asymmetric. Meanwhile, investigating the impact of the exchange rate on the balance in trade between Malaysia and Thailand, Bahmani-Oskooee and Aftab (2017) showed that depreciation increased the trade balance for most industries, and for 26 out of 61 industries, long-run effects were asymmetric. Bahmani-Oskooee and Harvey (2021b) focused on the asymmetric effects of volatility increases and decreases and its influence on US–Australia exports, finding that asymmetric effects exist in some sectors even where symmetric effects do not. Meanwhile, Xu, Bahmani-Oskooee, and Karamelikli (2021) analyzed China–US commodity trade, concluding that asymmetric and nonlinear methodologies yielded more accurate findings than symmetric and linear models. Their nonlinear analysis revealed a negative relationship between exchange rate volatility and trade, which was not evident in linear models (affecting 45% of US exports to China and 76% of Chinese exports to the US).

Methodology

The study utilized monthly data from May 2004 to July 2023 sourced from Eurostat, encompassing bilateral trade between Germany and the individual V3 countries. The dataset includes export and import values for ten one-digit SITC sectors, were taken. The period commences with the accession of the V3 countries to the European Union. Foreign exchange rates were obtained from the European Central Bank, while industrial production was retrieved from

the International Monetary Fund's International Financial Statistics (IFS) database. These three Visegrad countries represent significant trading partners for German, the largest regional economy; Slovakia is excluded because of its adoption of the euro and consequent lack of an independently floating currency. Table 1 provides an overview of the import and export structure between the V3 and Germany. These three major economies in Central Europe have the potential to exhibit their own unique trade patterns.

The trade balance for each partner country is calculated as the ratio of its exports to Germany (in €) to its imports from Germany. Consequently, balanced trade would yield a ratio of one, while a partner's trade surplus (German deficit) would yield a value greater than one. These values for the ten sectors for all three countries are presented in Figure 1.

An examination of Figure 1 reveals no clear pattern in trade flows across industries or countries. For example, Sector 7 (Machinery and transport equipment) shows a trade deficit for Poland but a surplus for Czechia. Similar inter-sectoral and inter-country variations are evident throughout the sample.

Table 1. Most important import and export sectors in May of each year

Czechia-Germany											
2004				2013				2023			
Sector	Exports	Sector	Imports	Sector	Exports	Sector	Imports	Sector	Exports	Sector	Imports
7	756 (49%)	7	588 (52%)	7	1110 (46%)	7	1569 (55%)	7	2028 (47%)	7	3659 (60%)
6	342 (22%)	6	208 (18%)	6	488 (20%)	6	492 (17%)	6	768 (18%)	6	826 (13%)
8	188 (12%)	8	179 (16%)	5	342 (14%)	8	324 (11%)	5	643 (15%)	8	778 (13%)
T	1541	T	1132	T	2433	T	2848	T	4355	T	6123
Hungary-Germany											
2004				2013				2023			
Sector	Exports	Sector	Imports	Sector	Exports	Sector	Imports	Sector	Exports	Sector	Imports
7	693 (62%)	7	632 (72%)	7	823 (57%)	7	1014 (65%)	7	1707 (62%)	7	2403 (74%)
6	202 (18%)	8	89 (10%)	6	238 (16%)	8	182 (12%)	6	375 (14%)	8	278 (9%)
5	83 (7%)	6	83 (9%)	5	161 (11%)	6	181 (12%)	5	274 (10%)	6	220 (7%)
T	1110	T	880	T	1446	T	1558	T	2742	T	3235
Poland-Germany											
2004				2013				2023			
Sector	Exports	Sector	Imports	Sector	Exports	Sector	Imports	Sector	Exports	Sector	Imports
7	697 (42%)	7	501 (40%)	7	1245 (36%)	7	1134 (37%)	7	2915 (40%)	7	3348 (41%)
6	463 (28%)	6	253 (20%)	6	739 (22%)	6	662 (22%)	6	1335 (18%)	8	1414 (17%)
5	249 (15%)	8	233 (19%)	5	601 (18%)	8	507 (16%)	5	1114 (15%)	6	1297 (16%)
T	1672	T	1249	T	3419	T	3075	T	7373	T	8151

€ millions, % of total exports – imports, T – total exports – imports.

Source: data from Eurostat and own calculations.

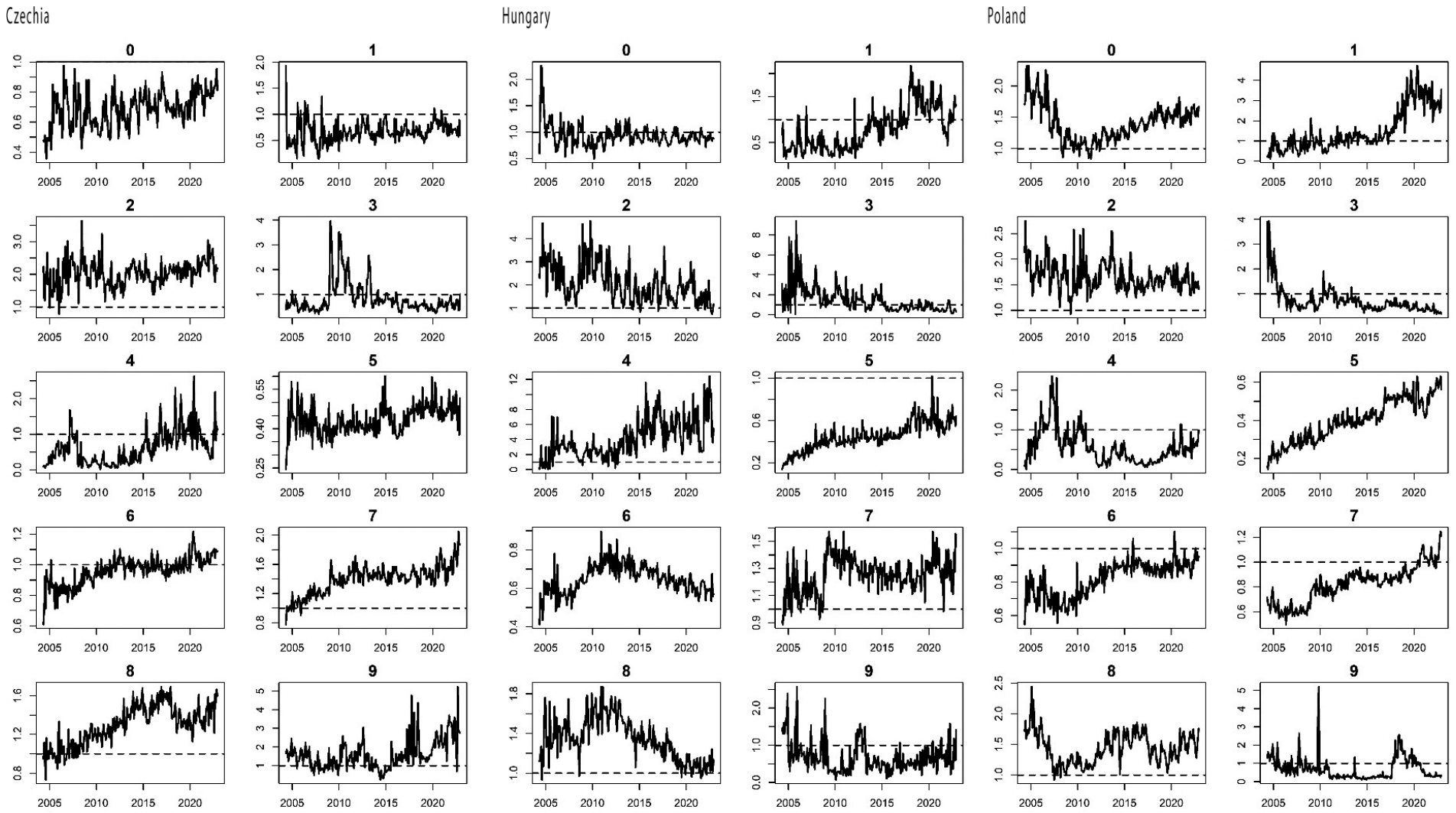


Figure 1. Bilateral trade balances with Germany

Sector titles are listed in Table 2. The horizontal line indicates balanced trade; values below this line represent a trade deficit.

Source: own calculations based on Eurostat data.

These balances serve as the dependent variable in a set of macroeconomic models. Following Bahmani-Oskooee and Hegerty (2009), as well as a host of related papers, the main determinants are domestic and foreign output (proxied by indices of industrial production), the real exchange rate, and a measure of exchange-rate volatility:

$$TB = f\left(IP^{H},\ IP^{F},\ q_i,\ qVOL\right). \tag{1}$$

Here, *TB* represents each individual sectoral trade balance, and IP^{H} and IP^{F} are domestic and foreign indices of industrial production. The real exchange rate is represented by *q*, which is itself calculated using both countries' Consumer Price Indices along with the nominal exchange rate. The exchange rate volatility measure is constructed using log changes in *q*. Following a GARCH(1,1) process (as in Bollerslev 1986) using an AR(1) process as the mean equation estimated for each country separately, the volatility is derived as:

$$\Delta \ln q_t = \alpha + \rho\, \Delta\, \ln q_{t-1} + \varepsilon_t, \tag{2a}$$

$$qVOL_t = h_t^2 = w + \varepsilon_{t-1}^2 + h_{t-1}^2. \tag{2b}$$

These are plotted to describe their behavior over time, before entering them into the models for the statistical analysis.

The main estimation techniques are the Autoregressive Distributed Lag (ARDL) cointegration approach of Pesaran, Shin, and Smith (2001), as well as its nonlinear extension, the NARDL methodology introduced by Shin, Yu, and Greenwood-Nimmo (2014). Natural logs are used for each variable.

The basic ARDL model for each country individually models the dependent variable (*y*) as a function of the independent variables (*x*, *z*, etc.) by combining both lagged level variables and first-differenced variables as follows:

$$\Delta y_t = \beta_0 + \sum_{i1=1}^{n1} \beta_{1i}\, \Delta\, y_{t-i} + \sum_{i2=0}^{n2} \beta_2\, \Delta\, x_{t-i} + \sum_{i3=1}^{n3} \beta_3\, \Delta\, z_{t-i} + \theta_1 y_{t-1} + \theta_2 x_{t-1} + \theta_3 z_{t-1} + \epsilon_t. \tag{3}$$

Each optimal lag length *n* is chosen by minimizing the Akaike Information Criterion. If a stable, cointegrating relationship among the variables exists, then all the short-run differenced variables would be zero, and only the lagged level variables would remain. This normalized vector would then yield long-run coefficient estimates.

An F-test for joint significance among these long-run coefficients is also conducted to provide evidence of cointegration. If the long-run variables are jointly significant, it indicates the presence of an equilibrium relationship among them, even if the short-run fluctuations are zero. The alternative hypothesis is that at least one of the variables is equal to zero.

This F-test is known as a "bounds test" because it is applicable to variables that are integrated of order 1 (nonstationary) or of order 0 (stationary). Therefore, it is not necessary to conduct unit-root testing to determine whether each variable is I(1) or I(0). Following Pesaran, Shin, and Smith

(2001), among others, critical values were calculated for two extremes: one in which all variables are I(0), and the other in which all are I(1). If the computed F-statistic exceeds the upper bound value, cointegration is confirmed. If it is less than the lower bound, it is definitively rejected. Intermediate cases can be assessed using an alternative test.

We expect that an increase in *Domestic income* (proxied by IP^H) will increase each V3 country's imports, thus reducing its trade balance. Similarly, increases in German income (proxied by IP^F) will raise V3 exports and trade balances. The real exchange rate (q), expressed as units per euro, is such that increases reflect a depreciation of the V3 currency, which will increase the trade balance. Exhange-rate volatility is often expected to reduce trade, though it may increase it in "risk-loving" industries. As McKenzie (1999) and Bahmani-Oskooee and Hegerty (2007) explain, the effect of exchange-rate volatility on trade flows is often ambiguous, particularly if traders hedge, limiting the impact of risk.

Using the nonlinear technique, the positive and negative effects of changes in an explanatory variable are assumed to be asymmetric. The variable of interest – in this case, changes to the log real exchange rate – is decomposed into its positive and negative components as follows:

$$POS_t = \sum_{i}^{t} \max(\Delta \ln q_t, 0), \tag{4a}$$

$$NEG_t = \sum_{i}^{t} \min(\Delta \ln q_t, 0). \tag{4b}$$

These two variables then replace the original q in the models. As Bahmani-Oskooee and Fariditavana (2016) note, if changes in the real exchange rate are to increase a country's trade balance, the coefficients on *POS* and *NEG* will both be significantly positive and similar in size.

Here, we also focus on the long-run estimates to show the effects of changes to income, relative prices, and risk on sectoral trade flows between the V3 countries and Germany. Overall, our results indicate that the effects vary by country, with sector 2, in particular, and Poland most affected by macroeconomic fluctuations. Our results are presented below.

Results and discussion

Figure 2 shows the volatilities that were generated using GARCH(1,1) processes. Volatility increased during the 2008 Global Financial Crisis. However, the secondary spike differs by country. While the Polish zloty registered a relatively small increase after 2020, there were two large spikes in the Czech koruna during that time. The Hungarian forint also experienced a lasting increase in volatility at that time.

The key focus of this study is the ARDL estimations and their long-run coefficient estimates. Table 2 shows the lag order, as well as the F-statistics for cointegration and R-bar-squared for goodness of fit. Most industries show evidence of cointegration (a significant joint test, with a p-value for the F-statistic below 0.05); notable exceptions are Sectors 5 and 8 for Czechia, Sectors 5 and 9 for Hungary, and a larger share of sectors for Poland (0, 3, 6, 7, 8, 9). This

insensitivity of Polish–German trade to the traditional macroeconomic determinants merits further study.

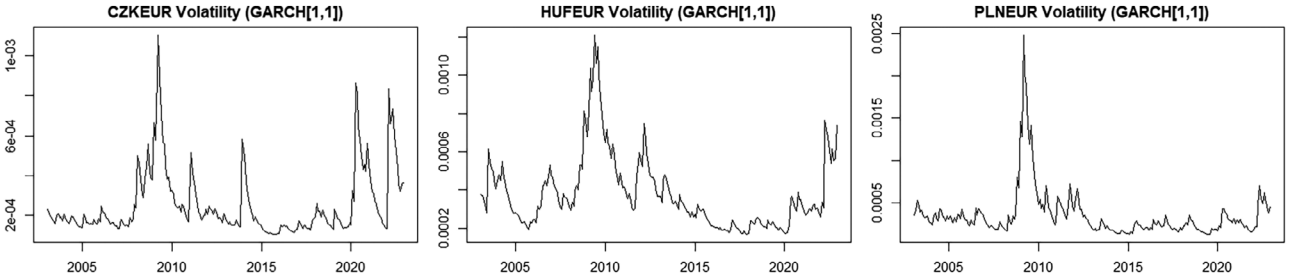


Figure 2. GARCH(1,1)-generated volatility series
Source: own calculations based on Eurostat data.

Table 2. ARDL Orders, Cointegration Tests, and Goodness of Fit

	Czechia			Hungary			Poland		
Ind.	ARDL Order	F (p-val.)	R2	ARDL Order	F (p-val.)	R2	ARDL Order	F (p-val.)	R2
0	(3,3,3,2,5)	6.788 (0.001)	0.395	(4,0,1,4,3)	10.456 (0.000)	0.329	(3,1,3,1,0)	2.665 (0.284)	0.775
1	(2,0,2,0,0)	10.826 (0.000)	0.210	(5,0,6,0,0)	4.917 (0.012)	0.694	(5,0,0,5,2)	6.187 (0.002)	0.773
2	(2,1,0,0,3)	10.511 (0.000)	0.227	(5,0,5,1,3)	11.372 (0.000)	0.529	(4,6,1,0,4)	9.066 (0.000)	0.317
3	(4,6,4,1,0)	5.568 (0.004)	0.712	(3,6,2,0,4)	5.455 (0.005)	0.482	(3,4,3,0,2)	4.261 (0.035)	0.697
4	(5,6,3,0,0)	5.659 (0.004)	0.654	(5,6,0,5,0)	4.880 (0.013)	0.515	(5,6,6,4,0)	1.943 (0.560)	0.733
5	(4,2,4,1,5)	3.350 (0.129)	0.424	(5,4,4,3,4)	2.799 (0.245)	0.784	(4,4,4,0,0)	4.746 (0.016)	0.909
6	(4,5,1,3,0)	4.506 (0.024)	0.684	(5,4,4,1,0)	3.513 (0.103)	0.584	(3,2,0,0,0)	2.494 (0.339)	0.725
7	(3,4,1,3,0)	5.665 (0.004)	0.773	(4,3,0,3,4)	5.496 (0.005)	0.402	(5,1,3,5,6)	2.434 (0.361)	0.905
8	(5,5,1,4,0)	1.614 (0.702)	0.784	(5,6,5,4,6)	9.564 (0.000)	0.747	(3,4,0,2,0)	3.300 (0.137)	0.719
9	(3,0,1,0,1)	3.52 (0.102)	0.481	(5,0,3,0,3)	2.802 (0.244)	0.282	(3,0,0,0,0)	3.164 (0.160)	0.665
	Sector Name								
0	Food and live animals								
1	Beverages and tobacco								
2	Crude mats, inedible, ex. fuels								
3	Min. fuels, lubricants and rel. mats								
4	Animal and veg oils, fats and waxes								
5	Chemicals and related prod, n.e.s.								
6	Manufactured goods								
7	Machinery and transport equipment								
8	Misc manufactured articles								
9	Commodities and trans., n.e.s.								

Source: own calculations based on data from Eurostat.

The long-run coefficients (Table 3) show that the key macroeconomic determinants of income and relative price are not universally significant in driving the three Visegrad countries' trade balances. Exchange rate risk appears to have even less of an effect. Czechia, for example, has seven sectors (0, 1, 2, 3, 4, 6, and 7) where cointegration is established. Hungary also has seven, which overlap Czechia's to some extent (0, 1, 2, 3, 4, 7, and 8). However, Poland has only four cointegrated specifications (1, 2, 3, and 5). Notably, industries where cointegration is common include beverages, crude materials, and mineral fuels. Meanwhile, commodities (Sector 9) and other manufactured goods are commonly not cointegrated. We can conjecture that the macroeconomic relationship specified in our model holds primarily for the former group rather than the latter.

Table 3. Long-Run ARDL Coefficients

Sector		Czechia	Hungary	Poland
0	Constant	– 3.117 (0.255)	**– 7.238 (0.047)**	– 3.137 (0.489)
	IP(H)	**0.861 (0.004)**	**– 0.414 (0.044)**	– 0.058 (0.805)
	IP(F)	– 0.544 (0.362)	**0.880 (0.035)**	– 0.294 (0.774)
	Q	0.465 (0.251)	0.876 (0.111)	**2.754 (0.007)**
	qVOL	0.034 (0.631)	– 0.005 (0.937)	– 0.138 (0.173)
1	Constant	2.661 (0.538)	**– 23.768 (0.024)**	**– 8.417 (0.041)**
	IP(H)	0.582 (0.219)	**1.886 (0.002)**	**2.024 (0.000)**
	IP(F)	– 0.788 (0.393)	1.069 (0.471)	– 1.497 (0.077)
	Q	– 0.813 (0.207)	1.237 (0.377)	**3.667 (0.010)**
	qVOL	– 0.054 (0.592)	– 0.300 (0.059)	– 0.095 (0.433)
2	Constant	– 2.518 (0.259)	**22.089 (0.000)**	1.937 (0.236)
	IP(H)	0.565 (0.052)	**– 0.659 (0.032)**	– 0.118 (0.178)
	IP(F)	0.149 (0.737)	**– 2.337 (0.003)**	– 0.225 (0.543)
	Q	0.330 (0.404)	– 1.493 (0.057)	– 0.308 (0.423)
	qVOL	**0.145 (0.021)**	– 0.129 (0.134)	– 0.072 (0.086)
3	Constant	**41.796 (0.000)**	17.307 (0.333)	1.418 (0.888)
	IP(H)	**– 3.829 (0.000)**	**– 2.885 (0.004)**	**– 1.115 (0.039)**
	IP(F)	– 1.683 (0.377)	0.233 (0.920)	1.993 (0.406)
	Q	**– 5.885 (0.000)**	– 0.816 (0.741)	– 3.47 (0.208)
	qVOL	– 0.346 (0.067)	0.003 (0.991)	0.136 (0.583)
4	Constant	**– 38.782 (0.000)**	– 7.676 (0.642)	**56.607 (0.018)**
	IP(H)	**9.204 (0.000)**	**2.136 (0.033)**	0.751 (0.525)
	IP(F)	**– 6.297 (0.002)**	– 2.127 (0.227)	**– 12.128 (0.029)**
	Q	**7.015 (0.000)**	1.131 (0.669)	– 5.125 (0.356)
	qVOL	– 0.128 (0.535)	– 0.27 (0.331)	– 0.336 (0.513)

Sector		Czechia	Hungary	Poland
5	Constant	– 1.880 (0.423)	2.218 (0.831)	**– 10.257 (0.000)**
	IP(H)	**0.776 (0.001)**	**1.417 (0.016)**	**0.935 (0.000)**
	IP(F)	– 0.898 (0.076)	– 0.498 (0.716)	0.876 (0.055)
	Q	0.452 (0.188)	– 1.271 (0.359)	0.787 (0.091)
	qVOL	– 0.013 (0.835)	0.021 (0.887)	0.033 (0.461)
6	Constant	1.725 (0.200)	10.124 (0.118)	– 2.070 (0.279)
	IP(H)	0.275 (0.068)	0.062 (0.847)	**0.348 (0.003)**
	IP(F)	– 0.257 (0.364)	– 0.792 (0.380)	– 0.251 (0.546)
	Q	**– 0.603 (0.003)**	– 1.235 (0.109)	0.866 (0.084)
	qVOL	– 0.014 (0.630)	0.016 (0.837)	– 0.002 (0.697)
7	Constant	**5.148 (0.004)**	**– 8.969 (0.046)**	– 1.571 (0.569)
	IP(H)	**0.460 (0.019)**	– 0.235 (0.327)	**0.845 (0.000)**
	IP(F)	**– 0.768 (0.037)**	0.885 (0.059)	– 0.360 (0.568)
	Q	**– 1.142 (0.000)**	**1.381 (0.047)**	– 0.030 (0.965)
	qVOL	– 0.040 (0.293)	**0.206 (0.004)**	0.107 (0.189)
8	Constant	2.234 (0.706)	**– 6.817 (0.030)**	– 1.138 (0.721)
	IP(H)	– 0.031 (0.965)	**– 1.114 (0.000)**	– 0.0020 (0.990)
	IP(F)	0.503 (0.678)	**1.755 (0.000)**	– 0.462 (0.504)
	Q	– 1.105 (0.215)	**1.012 (0.023)**	**1.967 (0.017)**
	qVOL	0.061 (0.653)	**0.188 (0.000)**	– 0.099 (0.202)
9	Constant	15.772 (0.117)	– 15.279 (0.527)	– 46.051 (0.065)
	IP(H)	2.178 (0.073)	0.138 (0.918)	– 1.706 (0.204)
	IP(F)	**– 4.789 (0.028)**	2.244 (0.504)	9.675 (0.069)
	Q	– 1.957 (0.229)	0.675 (0.836)	9.116 (0.134)
	qVOL	– 0.356 (0.176)	0.032 (0.934)	0.577 (0.304)

P-values in parentheses. Bold = significant at 5 percent.

Source: own calculations based on Eurostat data.

The long-run coefficients also highlight the limitations of the model. The expected signs – negative for Domestic IP, positive for Foreign IP, positive for q, and ambiguous for qVOL – rarely hold. Only in Sector 3 (mineral fuels and lubricants) does higher domestic income lead to increased imports in all three countries. A real appreciation of the euro helps V3 trade for two sectors in Poland (0 and 2: Food and Live Animals and Crude materials), confirming that the model holds better for primary materials. Czechia has a significantly positive coefficient in Sector 4, while Hungary exhibits a similar effect in Sector 7 (Machinery and Transport Equipment) – the only effect of this type, which likely reflects a distinctive aspect of the German–Hungarian trading relationship that warrants further investigation.

Table 4. NARDL Orders, Cointegration Tests, and Goodness of Fit

	Czechia			Hungary			Poland		
Industry	ARDL Order	F (p-val.)	R-bar-Sq.	ARDL Order	F (p-val.)	R-bar-Sq.	ARDL Order	F (p-val.)	R-bar-Sq.
0	(3,3,3,0,4,1)	7.276 (0.000)	0.394	(4,0,1,0,3,5)	8.844 (0.000)	0.268	(3,3,0,0,0,0)	3.415 (0.091)	0.765
1	(2,0,2,0,0,0)	8.403 (0.000)	0.197	(2,0,0,5,0,0)	5.483 (0.002)	0.686	(5,6,1,0,0,4)	3.346 (0.101)	0.774
2	(2,3,0,2,2,2)	7.715 (0.000)	0.255	(5,0,5,0,0,3)	9.607 (0.000)	0.519	(4,5,1,3,3,4)	11.38 (0.000)	0.381
3	(4,6,4,0,0,5)	3.498 (0.081)	0.705	(4,3,2,0,0,5)	3.425 (0.090)	0.481	(4,4,3,5,0,2)	4.987 (0.006)	0.687
4	(3,2,0,1,4,0)	4.447 (0.017)	0.664	(5,0,0,0,5,0)	6.213 (0.001)	0.530	(2,3,0,4,0,0)	3.592 (0.070)	0.719
5	(4,1,5,5,5,0)	4.276 (0.023)	0.457	(5,4,4,2,0,2)	4.077 (0.032)	0.788	(4,2,6,0,1,0)	4.804 (0.008)	0.908
6	(4,1,1,0,0,0)	3.407 (0.092)	0.670	(4,4,4,1,3,1)	2.836 (0.209)	0.590	(4,2,2,3,3,4)	1.612 (0.713)	0.736
7	(3,4,2,1,2,1)	4.166 (0.027)	0.761	(4,3,4,3,1,3)	4.397 (0.019)	0.394	(4,6,0,6,6,5)	3.395 (0.094)	0.913
8	(5,5,1,3,2,2)	1.355 (0.822)	0.790	(5,0,5,0,4,6)	7.736 (0.000)	0.745	(3,4,0,1,1,1)	3.070 (0.152)	0.717
9	(3,1,1,0,3,0)	3.140 (0.137)	0.486	(5,0,6,0,1,3)	3.224 (0.121)	0.266	(4,5,0,3,4,1)	1.873 (0.587)	0.664

Source: own calculations based on Eurostat data.

Given that changes in the real exchange rate have little effect across countries and sectors, we decompose the impacts into positive and negative changes via the Nonlinear ARDL (NARDL) approach. Table 4 presents the NARDL orders, F-tests, and goodness of fit statistics are given in Table 4. This method reveals cointegration in a larger number of industries than was the case when the linear ARDL model was applied. For Czechia, eight out of ten sectors (0, 1, 2, 3, 4, 5, 6, and 7, but not 8 or 9) have significant joint tests; the same is true for Hungary (0, 1, 2, 3, 4, 5, 7, and 8, but not 6 or 9). Poland shows cointegration in six sectors when this method is applied (sectors 0, 2, 3, 4, 5, and 7, but not 1, 6, 8, or 9). Notably, Sector 9 is never cointegrated in any country, which was also true with the linear ARDL model. Sectors 6 and 8 are not cointegrated for two of the three countries, while Sector 7 (Machinery) exhibits cointegration across all three countries.

The significance of the coefficients remains limited. Again, domestic income drives Sector 3, but the real exchange rate (*POS* and *NEG*) has few significant coefficients. The negative component is significantly positive in Czechia's Sectors 0 and 5, Hungary's Sectors 4, 5, and 7, and Poland's Sectors 2 and 5. This again highlights the model's strength in the primary-material sectors, as well as a common pattern in the Chemical sector. The positive component has a significant coefficient in Poland's Sectors 2 and 3 (negative), and 5 (positive). In the other two countries, only Hungary's Sector 7 has a significantly positive coefficient – which corresponds to the results from the linear ARDL model.

Table 5. Long-Run NARDL Coefficients

		Czechia	Hungary	Poland
0	Constant	– 0.227 (0.892)	– 2.230 (0.095)	5.745 (0.180)
	IP(H)	**0.655 (0.013)**	– 0.232 (0.121)	0.337 (0.235)
	IP(F)	– 0.643 (0.257)	0.604 (0.081)	– 1.843 (0.094)
	POS	0.069 (0.488)	– 0.002 (0.794)	1.610 (0.241)
	NEG	**0.423 (0.045)**	0.000 (0.985)	2.176 (0.202)
	qVOL	0.021 (0.706)	– 0.053 (0.378)	– 0.185 (0.164)
1	Constant	– 0.986 (0.728)	– 7.621 (0.055)	– 9.114 (0.176)
	IP(H)	0.819 (0.067)	**2.571 (0.000)**	**2.406 (0.000)**
	IP(F)	– 0.680 (0.472)	**– 1.939 (0.047)**	– 0.37 (0.829)
	POS	– 0.022 (0.903)	0.021 (0.632)	1.623 (0.330)
	NEG	0.113 (0.495)	– 0.015 (0.532)	0.277 (0.887)
	qVOL	0.017 (0.843)	**– 0.492 (0.010)**	0.041 (0.833)
2	Constant	0.294 (0.881)	**12.122 (0.000)**	**5.667 (0.000)**
	IP(H)	0.352 (0.194)	**– 1.077 (0.000)**	**– 0.168 (0.014)**
	IP(F)	0.196 (0.702)	**– 1.427 (0.022)**	– 0.479 (0.128)
	POS	– 0.632 (0.077)	– 0.003 (0.774)	**– 5.864 (0.000)**
	NEG	0.622 (0.062)	**0.022 (0.038)**	**5.990 (0.000)**
	qVOL	**0.238 (0.010)**	– 0.040 (0.621)	**0.222 (0.005)**

		Czechia	Hungary	Poland
3	Constant	7.048 (0.427)	11.397 (0.153)	– 6.519 (0.473)
	IP(H)	– 2.426 (0.080)	**– 2.774 (0.001)**	**– 1.232 (0.006)**
	IP(F)	2.013 (0.512)	0.766 (0.718)	3.673 (0.132)
	POS	0.039 (0.938)	– 0.017 (0.632)	**– 12.706 (0.033)**
	NEG	0.263 (0.589)	0.027 (0.487)	– 5.469 (0.082)
	qVOL	**0.631 (0.039)**	0.205 (0.513)	0.640 (0.076)
4	Constant	4.384 (0.651)	1.854 (0.783)	**42.76 (0.005)**
	IP(H)	**6.909 (0.000)**	**2.596 (0.000)**	– 0.021 (0.980)
	IP(F)	**– 10.036 (0.001)**	– 2.213 (0.141)	**– 8.542 (0.018)**
	POS	– 0.237 (0.800)	– 0.028 (0.393)	– 15.33 (0.071)
	NEG	– 0.189 (0.893)	**0.293 (0.012)**	6.404 (0.227)
	qVOL	**– 1.070 (0.009)**	0.251 (0.413)	0.390 (0.443)
5	Constant	3.432 (0.063)	– 4.344 (0.268)	**– 7.751 (0.000)**
	IP(H)	0.404 (0.087)	**1.146 (0.004)**	**1.004 (0.000)**
	IP(F)	**– 0.995 (0.042)**	0.031 (0.976)	0.571 (0.157)
	POS	**– 0.943 (0.017)**	– 0.064 (0.069)	– 0.410 (0.314)
	NEG	**0.840 (0.013)**	**0.047 (0.025)**	**1.915 (0.013)**
	qVOL	0.152 (0.127)	0.218 (0.110)	0.061 (0.178)
6	Constant	– 0.844 (0.528)	3.088 (0.308)	1.717 (0.513)
	IP(H)	0.427 (0.068)	– 0.306 (0.170)	**0.448 (0.000)**
	IP(F)	– 0.136 (0.772)	– 0.091 (0.896)	– 0.860 (0.117)
	POS	0.090 (0.329)	– 0.044 (0.111)	– 0.848 (0.683)
	NEG	**0.212 (0.029)**	0.053 (0.076)	2.187 (0.355)
	qVOL	0.063 (0.169)	0.177 (0.103)	– 0.009 (0.939)
7	Constant	– 2.917 (0.278)	0.494 (0.767)	– 0.167 (0.958)
	IP(H)	**0.901 (0.020)**	0.175 (0.260)	**0.883 (0.000)**
	IP(F)	– 0.341 (0.673)	– 0.249 (0.564)	– 0.296 (0.605)
	POS	1.027 (0.058)	**0.051 (0.033)**	– 0.362 (0.910)
	NEG	– 0.335 (0.417)	– 0.021 (0.243)	5.925 (0.185)
	qVOL	– 0.053 (0.652)	0.011 (0.885)	0.321 (0.152)
8	Constant	– 3.076 (0.466)	0.658 (0.491)	– 0.090 (0.981)
	IP(H)	0.411 (0.488)	**– 0.819 (0.000)**	0.289 (0.215)
	IP(F)	0.486 (0.687)	**1.030 (0.000)**	– 0.931 (0.287)
	POS	0.373 (0.608)	0.000 (0.954)	4.614 (0.107)
	NEG	0.562 (0.371)	0.013 (0.165)	– 6.613 (0.051)
	qVOL	0.093 (0.595)	**0.154 (0.000)**	**– 0.372 (0.033)**

		Czechia	Hungary	Poland
9	Constant	8.656 (0.199)	– 13.071 (0.237)	– 42.248 (0.157)
	IP(H)	**3.505 (0.004)**	0.449 (0.620)	– 0.626 (0.619)
	IP(F)	**– 5.956 (0.014)**	2.699 (0.340)	6.431 (0.275)
	POS	0.550 (0.248)	– 0.027 (0.503)	29.504 (0.158)
	NEG	– 0.616 (0.451)	0.076 (0.232)	– 38.864 (0.153)
	qVOL	– 0.325 (0.206)	0.250 (0.504)	– 1.516 (0.254)

P-values in parentheses. Bold = significant at 5 percent.

Source: own calculations based on Eurostat data.

Exchange-rate volatility, as expected, has an ambiguous effect on trade balances. It is negative in Sector 4 (Czechia) and 1 (Hungary) but is positive for Sectors 2 and 3 in Czechia, and Sector 2 in Poland. Notably, Sector 2 stands out due to its sensitivity to the overall macroeconomic environment across all three countries.

Two main results emerge here. First, while the macroeconomic model is stronger for primary-product sectors than for manufacturing, it appears weak overall. Second, the results appear idiosyncratic, warranting further detailed exploration to reveal country- and sector-specific dynamics, such as in Hungarian manufacturing. Additionally, common results across countries within a given sector, such as Chemicals, deserve similar investigation.

Our findings align with those of Bahmani-Oskooee, Halicioglu, and Hegerty (2016), who analyzed Mexico's trade with other countries and found that results depended on the country, sector, and model applied. Like Muteba and Dube (2014), Hasanov and Baharumshah (2014), and Bahmani-Oskooee, Harvey, and Hegerty (2014), we observe that the final effect depends on both the country and sector. This echoes the finding of Jiang and Liu (2023) for China and its major trading partners, Bao et al. (2023) for EU–India trade, Barkat et al. (2023) for GCC (Gulf Cooperation Council) countries, and Yaya (2021) for African countries. We further demonstrate the existence of differences between currency appreciation and depreciation for V3–Germany trade. Although Hall et al. (2010) noted that an open capital market reduces the influence of exchange rate risk on trade, and Svarnali et al. (2017) suggest a recent decrease in the interdependence between exchange rate and trade, we demonstrate that this relationship persists for certain sectors.

Following Bahmani-Oskooee, Harvey, and Hegerty (2017), who analyzed Japanese trade with twelve partners, we apply both linear and nonlinear models, showing that the latter reveals new relationships. Contrary to Wang (2023), who stresses that the depreciation of Chinese currency does not have a significant impact on US trade, and Aftab and Ismail (2018), who noted that exchange-rate volatility does not influence Chinese trade significantly, we demonstrate the existence of these interdependences for specific sectors.

As an additional robustness check, we investigate potential cyclical patterns or structural breaks in our exchange-rate series. This will allow us to determine whether periods of overvaluation or undervaluation exert differing influences on the trade balances in question. To achieve this,

we decompose each (log) rate using the Hodrick-Prescott filter. The preliminary results of this analysis are illustrated in Figure 3.

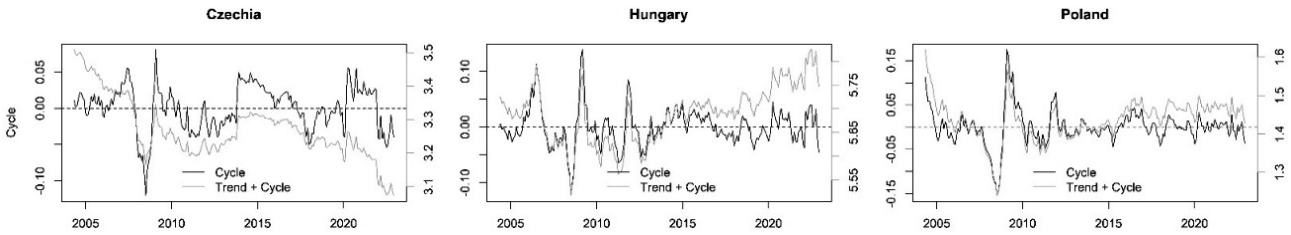


Figure 3. Real exchange rates (q) and their cyclical components
Source: own analysis based on Eurostat data.

The primary finding is that the cycles dominate the series, so there is little difference between them and the variables themselves. As a result, cyclical analysis might not be appropriate in this context. However, an unexpected finding is that for Hungary and Poland, the cycle and (trend + cycle) series deviated after an apparent break around 2015. For Czechia, the divergence seems to be persistent throughout the sample. Since a structural-break analysis falls outside the scope of the cointegration-based study provided here, we leave that for future research.

Conclusions

Since the introduction of cointegration models, many studies have re-examined the influence of exchange rates and their volatility on trade balances worldwide. Early research used aggregated data, while subsequent work incorporated sectoral differences. More recently, studies have considered asymmetric relationships, showing the distinct effects of positive and negative changes. While previous studies examined various country pairs, none focused on V3–Germany trade, a notable omission given the deep German–Central European supply chains that have existed since the 1990s.

Furthermore, existing research has yielded ambiguous results, depending on the research method, countries, and sectors analyzed. Although many studies analyzed the influence of exchange rate depreciation and appreciation on trade between developed and developing countries, few consider exchange rate risk, and ever fewer consider output. Our study addresses this gap.

We focus on the long-run estimates to show how changes in income, relative prices, and risk affect sectoral trade flows between the V3 countries and Germany. The paper adds value in the following respects. We find a weak link between these trade flows and their macroeconomic determinants, though primary products have the strongest connections. We also identify important sectoral and country-specific effects that merit further investigation. Additionally, we observe that the import-export structure of the V3 countries remained relatively unchanged over the examined period.

Another added value of this paper is the methodology, which considered both linear (ARDL) and nonlinear models (NARDL) together with asymmetries in response to the examined variables. In contrast to Sankaran, Krishna, and Vadivel (2021), who found that industrial production boosts

exports in emerging economies, Chit, Rizov, and Willenbockel (2010), who demonstrated a negative influence of exchange rate volatility for exports in five emerging Asian economies, and Wa Cipamba (2015), who noted that GDP stimulates exports in South Africa, our results indicate that these relationships are not universal and depend on the sector in question. Consistent with Bahmani-Oskooee and Hegerty (2009), but for different countries, we show that exchange rate volatility, the real exchange rate, and industrial production significantly influence trade flows for certain industries.

Furthermore, our findings also show that the current economic environment is more complex than that studied by Alexander (1952), Mundell (1963), and Davidson (2009). They align more with Kashi and Lynn (2012) and Muteba and Dube (2014), who showed that sectors react differently, and with Bosupeng, Naranpanawa, and Su (2024), who found that the influence depends on the country.

These conclusions have important implications for policymakers, investors, business owners and central bank authorities, who should consider them when making decisions that affect the examined variables, as these decisions may have far-reaching consequences. Policymakers can stimulate certain sectors to increase industrial production and manage the trade balance. Governments can stimulate exports by creating stimuli for industrial production in certain sectors. Business owners should consider them while preparing market risk hedging strategies, either with financial derivative instruments or traditional methods. Central banks, through their interest rate policies, influence both the real exchange rate and its volatility. Investors especially those who speculate should be aware that their actions in the foreign exchange market may have far-reaching consequences for the real economy.

Acknowledgement

The research was conducted during Izabela's research stay in Northeastern Illinois University in Chicago in 2024 and was supported by the Polish National Agency for Academic Exchange under the Strategic Partnerships programme, grant number BPI/PST/2021/1/00069/U/00001.

References

Abolagba, E.O., Onyekwere, N.C., Agbonkpolor, B.N., Umar, H.Y. (2010), *Determinants of agricultural exports*, "Journal of Human Ecology", 29 (3), pp. 181–184.

Aftab, M., Ismail, I. (2018), *Impact of currency reform on Chinese external trade*, "International Journal of China Studies", 9 (1), pp. 67–78.

Akbostanci, E. (2004), *Dynamics of the Trade Balance: The Turkish J-Curve*, "Emerging Markets Finance and Trade" 40 (5), pp. 57–73, https://doi.org/10.1080/1540496X.2004.11052584

Alexander, S.S. (1952), *Effects of a Devaluation on a Trade Balance*, "Staff Papers-International Monetary Fund", 2 (2), pp. 263–278.

Ali, M.M., Muzammil, M., Umar, A. (2022), *The Exchange Rate Volatility and Exports Growth of the Selected Developed Economies*, "Journal of Economic Impact", 4 (2), pp. 51–57, https://doi.org/10.52223/jei4022206

Auboin, M., Ruta, M. (2013), *The relationship between exchange rates and international trade: a literature review*, "World Trade Review", 12 (3), pp. 577–605, https://doi.org/10.1017/S1474745613000025

Awokuse, T.O. (2005), *Exports, economic growth and causality in Korea*, "Applied Economics Letters", 12 (11), pp. 693–696, https://doi.org/10.1080/13504850500188265

Bahmani-Oskooee, M. (1991), *Is there a long-run relation between the trade balance and the real effective exchange rate of LDCs?*, "Economics Letters", 36 (4), pp. 403–407, https://doi.org/10.1016/0165-1765(91)90206-Z

Bahmani-Oskooee, M., Aftab, M. (2017), *Asymmetric Effects of Exchange Rate Changes and the J-curve: New Evidence from 61 Malaysia–Thailand Industries*, "Review of Development Economics", 21 (4), e30–e46, https://doi.org/10.1111/rode.12298

Bahmani-Oskooee, M., Cheema, J. (2009), *Short-run and long-run effects of currency depreciation on the bilateral trade balance between Pakistan and her major trading partners*, "Journal of Economic Development", 34 (1), pp. 19–41, https://doi.org/10.35866/caujed.2009.34.1.002

Bahmani-Oskooee, M., Fariditavana, H. (2016), *Nonlinear ARDL Approach and the J-Curve Phenomenon*, "Open Economies Review", 27 (1), pp. 51–70, https://doi.org/10.1007/s11079-015-9369-5

Bahmani-Oskooee, M., Halicioglu, F., Hegerty, S.W. (2016), *Mexican bilateral trade and the J-curve: An application of the nonlinear ARDL model*, "Economic Analysis and Policy", 50 (C), pp. 23–40, https://doi.org/10.1016/j.eap.2016.02.003

Bahmani-Oskooee, M., Harvey, H. (2021a), *Are the effects of exchange-rate volatility on commodity trade between the U.S. and Mexico symmetric or asymmetric?*, "International Journal of Finance and Economics", 26 (2), pp. 2998–3027, https://doi.org/10.1002/ijfe.1947

Bahmani-Oskooee, M., Harvey, H. (2021b), *Exchange rate volatility and commodity trade between United States and Australia: An asymmetric analysis*, "The World Economy", 44 (6), pp. 1509–1700, https://doi.org/10.1111/twec.13057

Bahmani-Oskooee, M., Harvey, H., Hegerty, S.W. (2014), *Industry trade and exchange-rate fluctuations: Evidence from the U.S. and Chile*, "International Review of Economics and Finance", 29 (C), pp. 619–626, https://doi.org/10.1016/j.iref.2013.10.001

Bahmani-Oskooee, M., Harvey, H., Hegerty, S.W. (2017), *The Japanese trade balance and asymmetric effects of yen fluctuations: Evidence using nonlinear methods*, "The Journal of Economic Asymmetries", 15 (C), pp. 56–63, https://doi.org/10.1016/j.jeca.2017.02.001

Bahmani-Oskooee, M., Hegerty, S.W. (2007), *Exchange rate volatility and trade flows: a review article*, "Journal of Economic Studies", 34 (3), pp. 211–255, https://doi.org/10.1108/01443580710772777

Bahmani-Oskooee, M., Hegerty, S.W. (2009), *The Effects of Exchange-Rate Volatility on Commodity Trade between the United States and Mexico*, "Southern Economic Journal", 75 (4), pp. 1019–1044, https://doi.org/10.1002/j.2325-8012.2009.tb00945.x

Bahmani-Oskooee, M., Hegerty, S.W., Harvey, H. (2013), *Empirical tests of the Marshall-Lerner condition: a literature review*, "Journal of Economic Studies", 40 (3), pp. 411–443, https://doi.org/10.1108/01443581311283989

Bahmani-Oskooee, M., Hegerty, S.W., Zhang, R. (2014), *The Effects of Exchange-Rate Volatility on Korean Trade Flows: Industry-Level Estimates*, "Economic Papers", 33 (1), pp. 76–94, https://doi.org/10.1111/1759-3441.12064

Bahmani-Oskooee M., Kutan, A.M. (2009), *The J-curve in the emerging economies of Eastern Europe*, "Applied Economics", 41 (20), pp. 2523–2532, https://doi.org/10.1080/00036840701235696

Bao, H.H.G., Le, H.P., Nguyen, B.H., Vu, A. (2023), *The US dollar and trade balance: New findings from the international trade of India with the European Union*, "Cogent Business and Management", 10 (2), 2235817, https://doi.org/10.1080/23311975.2023.2235817

Barkat, K., Jarallah, S., Alsamara, M. (2024), *Do Exchange Rate Changes Improve the Trade Balance in GCC Countries: Evidence from Nonlinear Panel Cointegration*, "The International Trade Journal", 38 (2), pp. 184–200, https://doi.org/10.1080/08853908.2022.2121341

Bollerslev, T. (1986), *Generalized autoregressive conditional heteroskedasticity*, "Journal of Econometrics", 31 (3), pp. 307–327, https://doi.org/10.1016/0304-4076(86)90063-1

Bosupeng, M., Naranpanawa, A., Su, J.J. (2024), *Does exchange rate volatility affect the impact of appreciation and depreciation on the trade balance? A nonlinear bivariate approach*, "Economic Modelling", 130 (C), 106592, https://doi.org/10.1016/j.econmod.2023.106592

Chit, M.M., Rizov, M., Willenbockel, D. (2010), *Exchange Rate Volatility and Exports: New Empirical Evidence from the Emerging East Asian Economies*, "The World Economy", 33 (2), pp. 239–263, https://doi.org/10.1111/j.1467-9701.2009.01230.x

Clark, P.B. (1973), *Uncertainty, exchange risk, and the level of international trade*, "Economic Inquiry", 11 (3), pp. 302–313, https://doi.org/10.1111/j.1465-7295.1973.tb01063.x

Davidson, P. (2009), *The Keynes Solution. The Path to global Economic Prosperity*, Palgrave Macmillan, New York.

Geldner, T. (2024), *Exchange rates and trade balance dynamics: a quantile regression analysis*, "Applied Economics", 57 (10), pp. 1070–1104, https://doi.org/10.1080/00036846.2024.2311067

Giovannini, A. (1988), *Exchange rates and traded goods prices*, "Journal of International Economics", 24 (1–2), pp. 45–68, https://doi.org/10.1016/0022-1996(88)90021-9

Hacker, R.S., Hatemi-J, A. (2003), *How productivity and domestic output are related to exports and foreign output in the case of Sweden*, "Empirical Economics", 28 (4), pp. 767–782, https://doi.org/10.1007/s00181-003-0158-4

Hall, S., Hondroyiannis, G., Swamy, P.A.V.B., Tavlas, G., Ulan, M. (2010), *Exchange-rate volatility and export performance: Do emerging market economies resemble industrial countries or other developing countries?*, "Economic Modelling", 27 (6), pp. 1514–1521, https://doi.org/10.1016/j.econmod.2010.01.014

Hasanov, A.S., Baharumshah, A.Z. (2014), *Exchange-Rate Risk and Exports: Evidence from a Set of Transition Economies*, "Problems of Economic Transition", 57 (1), pp. 80–101, https://doi.org/10.2753/PET1061-1991570105

Hooper, P., Kohlhagen, S.W. (1978), *The effect of exchange rate uncertainty on the prices and volume of international trade*, "Journal of International Economics", 8 (4), pp. 483–511, https://doi.org/10.1016/0022-1996(87)90001-8

International Monetary Fund (2013), *German-Central European Supply Chain-Cluster Report: Staff Report, First Background Note, Second Background Note, Third Background Note*, "IMF Staff Country Reports", 2013 (263), https://doi.org/10.5089/9781484347225.002

Jianga, W., Liu, G. (2023), *The asymmetric impact of exchange rate changes on bilateral trade balance: evidence from China and its trade partners*, "Economic Research – Ekonomska Istrazivanja", 36 (2), 2129408, https://doi.org/10.1080/1331677X.2022.2129408

Kashi, K.R., Lynn, K.P. (2012), *Exchange Rate Volatility and Bilateral Agricultural Trade Flows: The Case of the United States and OECD Countries*, 2012 Annual Meeting, February 4–7, Southern Agricultural Economics Association, Birmingham, https://doi.org/10.22004/ag.econ.119736

Khouiled, B., Chini, S., Benrouina, M. (2023), *Dynamic relationship between exchange rate and trade balance*, "SocioEconomic Challenges (SEC)", 7 (3), pp. 164–173, https://doi.org/10.61093/sec.7(3).164-173.2023

McKenzie, M.D. (1999), *The Impact of Exchange Rate Volatility on International Trade Flows*, "Journal of Economic Surveys", 13 (1), pp. 71–104, https://doi.org/10.1111/1467-6419.00075

Mundell, R.A. (1963), *Capital mobility and stabilization policy under fixed and flexible exchange rates*, "Canadian Journal of Economics and Political Science/Revue canadienne de economiques et science politique", 29 (4), pp. 475–485.

Mundell, R.A. (1971), *The dollar and the policy mix: 1971*, "Essays in International Finance", 85, pp. 1–34.

Muteba, M.J., Dube, S. (2014), *The impact of exchange rate volatility on international trade between South Africa, China and USA: The case of the manufacturing sector*, "MPRA Paper 64389", University Library of Munich, Munich.

Narayan, P.K., Smyth, R. (2006), *The dynamic relationship between real exchange rates, real interest rates and foreign exchange reserves: empirical evidence from China*, "Applied Financial Economics", 16 (9), pp. 639–651, https://doi.org/10.1080/09603100500401278

Omer, M., Kamal, J., Haan, J. (2023), *Does an exchange rate depreciation improve the trade balance of Pakistan?*, "International Journal of Economic Policy Studies", 17 (1), pp. 163–185, https://doi.org/10.1007/s42495-022-00096-3

Pesaran, M.H., Shin, Y., Smith, R.J. (2001), *Bounds Testing Approaches to the Analysis of Level Relationships*, "Journal of Applied Econometrics", 16 (3), pp. 289–326.

Pruchnicka-Grabias, I., Piekunko-Mantiuk, I., Hegerty, S.W. (2024), *Poland–USA sectoral trade balances: regime shifts and the nonlinear impact of currency fluctuations*, "Central European Management Journal", 32 (1), pp. 116–133, https://doi.org/10.1108/CEMJ-10-2022-0161

Puah, Ch.H., Yong, S.W., Shazali, A.M.S.A., Lau, E. (2008), *Exchange rate and balance nexus in ASEAN-5*, "Labuan Bulletin of International Business and Finance", 6, pp. 19–37.

Ren, P., Sakouba, I. (2024), *Exchange Rate Movements and China-East Africa Trade Balance: A New Perspective From RMB*, "Sage Open", 14 (1), https://doi.org/10.1177/21582440241230805

Rose, A.K., Yellen, J.L. (1989), *Is there a J-curve?*, "Journal of Monetary Economics", 24 (1), pp. 53–68, https://doi.org/10.1016/0304-3932(89)90016-0

Sankaran, A., Krishna, A., Vadivel, A. (2021), *How does manufacturing output affect export behaviors in emerging market economies? Evidence from a dynamic panel ARDL for ten biggest emerging market economies*, "Future Business Journal", 7, 26, https://doi.org/10.1186/s43093-021-00072-x

Sharma, S.C., Dhakal, D. (2006), *Causal analyses between exports and economic growth in developing countries*, "Applied Economics", 26 (12), pp. 1145–1157, https://doi.org/10.1080/00036849400000112

Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014), *Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework*, [in:] R.C. Sickles, W.C. Horrace (eds.), *Festschrift in Honor of Peter Schmidt: Econometric Methods and Applications*, Springer Science & Business Media, New York, pp. 281–314, https://doi.org/10.1007/978-1-4899-8008-3_9

Siddique, M., Anwar, A., Quddus, M.A. (2020), *The impact of real effective exchange rate on revealed comparative advantage and trade balance of Pakistan*, "Economic Journal of Emerging Markets", 12 (2), pp. 193–207, https://doi.org/10.20885/ejem.vol12.iss2.art6

Šimáková, J. (2014), *The Effects of Exchange Rate Change on the Trade Balance of Slovakia*, "European Financial and Accounting Journal", 9 (3), pp. 50–66, https://doi.org/10.18267/j.efaj.124

Šimáková, J. (2016), *Cointegration Approach to the Estimation of the Long-Run Relations between Exchange Rates and Trade Balances in Visegrad Countries*, "Financial Assets and Investing", 7 (3), pp. 1–21, https://doi.org/10.5817/FAI2016-3-3

Šimáková, J., Stavarek, D. (2015), *The effect of the exchange rate on industry-level trade flows in Czechia*, "Finance", 18 (4), pp. 150–165, https://doi.org/10.15240/tul/001/2015-4-011

Tyler, W.G. (1981), *Growth and export expansion in developing countries: Some empirical evidence*, "Journal of Development Economics", 9 (1), pp. 121–130, https://doi.org/10.1016/0304-3878(81)90007-9

Wa Cipamba, P.C. (2015), *The Export-Output Relationship in South Africa: An Empirical Investigation*, "Studies in Economics and Econometrics", 39 (1), pp. 25–46, https://doi.org/10.1080/10800379.2015.12097275

Wang, K., Barrett, Ch.B. (2007), *Estimating the Effects of Exchange Rate Volatility on Export Volumes*, "Journal of Agriculture and Resource Economics", 32 (2), pp. 225–255, https://doi.org/10.22004/ag.econ.8643

Wang, Y. (2023), *Asymmetric long-run effect of exchange rate on bilateral trade balance between USA and China*, "Journal of Chinese Economic and Foreign Trade Studies", 16 (2), pp. 85–98, https://doi.org/10.1108/JCEFTS-03-2022-0020

Xu, J., Bahmani-Oskooee, M., Karamelikli, H. (2022), *On the link between U.S. – China commodity trade and exchange rate uncertainty: An asymmetric analysis*, "Australian Economic Papers", 61 (1), pp. 87–137, https://doi.org/10.1111/1467-8454.12241

Czy zmiany kursu walutowego wykazują asymetryczny wpływ na handel zagraniczny pomiędzy krajami Grupy Wyszehradzkiej i Niemcami?

Zrozumienie determinant przepływów handlowych pomiędzy krajami jest szczególnie ważną kwestią dla decydentów, banków centralnych i inwestorów. Artykuł bada długoterminowy wpływ realnego kursu walutowego i jego zmienności, jak również produkcji na bilanse handlowe 10 sektorów SITC pomiędzy krajami Grupy Wyszehradzkiej i Niemcami. W związku z tym, że liniowy model ARDL pokazał niewielki wpływ dla krajów i sektorów, przeprowadzono dekompozycję tych wpływów na wpływy pozytywne i negatywne za pomocą nieliniowego modelu NARDL. Artykuł tworzy wartość dodaną w następujących kwestiach. Po pierwsze, podczas gdy determinanty makroekonomiczne mają względnie słaby związek z bilansem obrotów bieżących, najmocniejsze zależności widać w podstawowych sektorach. Po drugie, chociaż większość badanych przepływów uzależniona jest od kraju, sektora, zastosowanej metody, badania wskazują na jednoznaczne rezultaty, na przykład dotyczące sektora chemicznego we wszystkich krajach oraz produkcyjnego na Węgrzech. Po trzecie, nieliniowe modele wskazują na występowanie kointegracji pomiędzy realnym kursem walutowym i bilansem handlowym pomiędzy analizowanymi krajami dla większości badanych przemysłów, choć długoterminowe współczynniki pozostają nieistotne w wielu przypadkach.

Słowa kluczowe: bilans handlowy, Grupa Wyszehradzka, zmienność kursu walutowego, asymetryczne efekty

Comparative Economic Research. Central and Eastern Europe
Volume 29 Number 1, 2026
https://doi.org/10.18778/1508-2008.29.02

Energy Security and Sustainable Development of the Energy Sector: Comparative Analysis of the Visegrad Group Countries

Adam Sadowski https://orcid.org/0000-0002-8608-5118
Associate Professor, University of Lodz, Faculty of Management, Lodz, Poland,
e-mail: adam.sadowski@uni.lodz.pl

Magdalena Kowalska https://orcid.org/0000-0002-5821-0305
Ph.D., University of Lodz, Faculty of Economics and Sociology, Lodz, Poland,
e-mail: magdalena.kowalska@uni.lodz.pl

Anna Misztal https://orcid.org/0000-0002-7455-5290
Associate Professor, University of Lodz, Faculty of Economics and Sociology, Lodz, Poland,
e-mail: anna.misztal@uni.lodz.pl

Agata Gniadkowska-Szymańska https://orcid.org/0000-0002-7321-3360
Ph.D., University of Lodz, Faculty of Economics and Sociology, Lodz, Poland,
e-mail: agata.gniadkowska@uni.lodz.pl

Agnieszka Piotrowska-Piątek https://orcid.org/0000-0002-6620-5485
Ph.D., Kielce University of Technology, Faculty of Management and Computer Modelling, Kielce, Poland,
e-mail: apiotrowska@tu.kielce.pl

Dorota Starzyńska https://orcid.org/0000-0001-5355-016X
Ph.D., University of Lodz, Faculty of Management, Lodz, Poland, e -mail: dorota.starzynska@uni.lodz.pl

Per Engelseth https://orcid.org/0000-0003-1559-7471
Ph.D., Full Professor, UiT The Arctic University of Norway, Tromso, Norway, e-mail: per.engelseth@uit.no

Funding information: A.S. – University of Lodz, Faculty of Management, Lodz, Poland; M.K. – University of Lodz, Faculty of Economics and Sociology, Lodz, Poland; A.M. – Associate Professor, University of Lodz, Faculty of Economics and Sociology, Lodz, Poland; A.G.-S. – University of Lodz, Faculty of Economics and Sociology, Lodz, Poland; A.P.-P. – Kielce University of Technology, Faculty of Management and Computer Modelling, Kielce, Poland; D.S. – University of Lodz, Faculty of Management, Lodz, Poland; P.E. – UiT The Arctic University of Norway, Tromso, Norway.
The percentage share of the Authors in the preparation of the work is: A.S. – 14.29%, M.K. – 14.29%, A.M. – 14.29%, A.G.-S. – 14.29%, A.P.-P. – 14.29%, D.S. – 14.29%, P.E. – 14.29%.
Declaration regarding the use of GAI tools: Not used.
Conflicts of interests: None.
Ethical considerations: The Authors assure of no violations of publication ethics and take full responsibility for the content of the publication.
Received: 23.04.2025. Verified: 26.05.2025. Accepted: 29.01.2026

Abstract

A sustainable energy sector is crucial for a country's stable and environmentally friendly socioeconomic development. Economic security (ES), the basis for the functioning of the state, is one of the major factors affecting the development. The objective of this article is to examine how ES influenced the sustainable development of the energy sector in the Visegrad Group countries, i.e., Poland, Slovakia, Hungary, and Czechia, over the period spanning from 2008 to 2020. To evaluate a meaningful relationship between the indicators ($p < 0.05$), we used correlation coefficients, the ordinary least squares method, and the seemingly unrelated regression model. The findings indicate that ES impacts the sustainable development of the energy sector, where positive results can be achieved by implementing coordinated macroeconomic policies. Green energy sources and renewable energy are crucial in this process.

Keywords: energy sector, sustainable development, economic security

JEL: O13, O40

Introduction

The current development of the energy sector includes three basic pillars: economic (E), social (S), and environmental (Env) (Misztal, Kowalska, and Fajczak-Kowalska 2022). It is crucial for global sustainable development goals (SDGs) and national security (Prasad et al. 2019). Therefore, proactive steps must be taken to drive energy transformation and integrate renewable energy sources (Cergibozan 2022).

Sustainable development (SD) depends on external, geopolitical, macrosocial, technological, and internal factors related to the financial and economic situation of the energy sector (Sebestyén 2021). SD has been the subject of several theoretical and empirical analyses (Komarnicka and Murawska 2021; Misztal, Kowalska, and Fajczak-Kowalska 2022). As a rule, progress in SD is positively correlated with socioeconomic development, access to new technological solutions, and society's ecological awareness (Halkos and Gkampoura 2020; Razmjoo et al. 2021; Wahab et al. 2021).

A novelty of our paper is the study of the impact of economic security (ES) on the sustainable energy sector, with the aim of identifying SD and ES indicators in the Visegrad Group countries, i.e., Poland, Slovakia, Hungary, and Czechia. Our research contributes to the theory of SD by proposing a conceptual framework that defines the relationship between SD and the energy sector.

The main objective of our research was to determine the impact of energy security on the SD of the energy sector of the Visegrad Group countries between 2008 and 2020. The basic research hypothesis is formulated as follows:

Economic security positively influences the sustainable development of the energy sector, though the magnitude and pathways of this effect vary significantly across Visegrad countries due to differences in macroeconomic stability, energy policy, and innovation capacity.

This assumption results from differences in sectoral development in those countries, varying levels of innovation, and different policies for the implementation of renewable energy sources. In addition, we wanted to answer the following research questions:

1. Does sustainable development in the studied countries demonstrate positive growth dynamics?
2. What are the dynamics of economic security?
3. Does the impact of economic security on the pillars of sustainable development differ across countries, or are there similarities among them?

In our analysis, we applied correlation coefficients (Pearson's r, Spearman's rho, Goodman-Kruskal's gamma, and Kendall's tau), the ordinary least squares (OLS) method, and the seemingly unrelated regression (SUR) model.

We verified the classical OLS assumptions, including:

- Absence of multicollinearity among independent variables (via Variance Inflation Factor, VIF)
- Homoskedasticity (Breusch-Pagan test)
- Normality of residuals (Jarque-Bera test)
- No autocorrelation (Durbin-Watson statistic)

We developed original analytical indicators for ES and SD designed to assess energy policy transformations towards SD by European Union institutions.

The study comprises six parts. Part Two describes the theoretical foundations of the study and presents SD in the energy sector and ES in the Visegrad Group countries. Part Three presents the research methodology, which involves econometric models. Part Four describes in detail the results of our research, while Part Five discusses the results. The closing part contains the final conclusions and directions for future research.

Data for the analysis were obtained from Eurostat, while calculations were performed using Statistica and Gretl software.

Literature review

Sustainable development of the energy sector: definition and determinants

SD comprises three basic components: economic, social, and environmental (Misztal Kowalska, and Fajczak-Kowalska 2022). For enterprises, it entails conducting business in a way that not only yields specific economic and financial results but also improves working conditions and quality of work while minimizing negative environmental impacts (Silvestre and Ţîrcă 2019; Bose and Khan 2022). It also ensures the fulfillment of objectives for both current and future stakeholders (Bogołębska, Feder-Sempach, and Stawasz-Grabowska 2019; Zhou et al. 2022; Wang, Chen, and Li 2022). It enables current development without compromising the potential for future growth (Colbert and Kurucz 2007), while also promoting shared value (Porter and Kramer 2007). The term "sustainable development of enterprises" is also defined as a process that reduces resource consumption while generating added value for customers and business partners (Giovannoni and Fabietti 2013; Silvestre and Ţîrcă 2019; Thacker et al. 2019).

In the energy sector, SD considers socioeconomic issues (Lu et al. 2019; Kamran, Fazal, and Mudassar 2020). Its main objective is to meet market demands, safeguard national energy security, and protect the natural environment (Valentine 2011; Gong 2022). This sector plays a key role in ensuring stable and sustainable economic growth, and a key manifestation of progress is a change in the country's energy balance towards renewable energy sources (Stern 2011; Zahoor, Khan, and Hou 2022).

SD in the energy sector is influenced by a variety of internal and external factors. Internal factors encompass financial and non-financial resources, economic performance, business development models, and strategic approaches. External factors include the macroeconomic situation, social and geopolitical conditions, market structure and the possibilities of implementing new technologies (Pieloch-Babiarz, Misztal, and Kowalska 2021; Kuzma and Sehnem 2022; Khan, Khurshid, and Cifuentes-Faura 2023). ES is also a factor that affects SD across all economic sectors.

Economic security

ES is a key component of national security. It is a heterogeneous, complex, and multithreaded concept that largely shapes quality-of-life standards for entire social groups, individually, locally, and internationally (Koval et al. 2019; Likhonosova et al. 2023).

ES forms the foundation of the state and is closely linked to its economy and society. It encompasses various areas of economic life and involves the complicated structure of the economic system and its environment. However, it is mainly associated with the efficiency and capacity of the economy. ES comprises aspects such as economic prosperity, high living standards, and free access to commodity and financial markets (Cable 1995; Hobela and Melnyk 2021).

ES addresses the risks that could affect prosperity, unrestricted market access, financial stability, and the availability of natural resources while also safeguarding the state's position and continued development. It is associated with all the elements of the state, including its territory, society, and government. In territorial terms, ES means maintaining territorial cohesion as an important factor in controlling the economy. For society, it translates into stability, improved living conditions, and a better quality of life. In relation to the state and its government, ES combines the independence of both internal and foreign policy (Akimov et al. 2020; Armstrong and Urata 2021).

ES is often defined as involving three components: financial aspects, raw materials, and food (Dźwigoł et al. 2019; Lee, Xing, and Lee 2022; Štreimikienė et al. 2022). It is, therefore, the basis for the functioning of the state, ensuring sustainable economic growth, increasing employment and investment, balanced fiscal relations, and positive foreign trade. However, ES can only be built upon transparent and stable economic goals, as they are the cornerstone of the development programming process.

Economic security and sustainable energy development in the Visegrad countries: an overview of previous research results

Energy security refers to the state of the economy that ensures current and future energy and fuel demands are met in a technically and economically viable manner while complying with environmental protection requirements. The continuity of electricity supply is an indispensable condition for the existence and continuous development of modern societies (Lee, Xing, and Lee 2022).

A country's energy security is influenced by numerous elements, including the availability of domestic energy resources, the origin and degree of diversification of supply sources, the amount of accumulated reserves, the level of development of renewable energy sources, the form of ownership of the supply system enterprises, and the energy sector as a whole (Alper and Oguz 2016; Ahmad et al. 2022; Marra and Colantonio 2022).

The energy sector's SD occurs within well-defined socioeconomic conditions. Energy security and its sustainable growth are essential components of overall ES. On the other hand, general ES influences decisions made within the energy sector (Siksnelyte et al. 2018; Hosseini 2020; Heffron et al. 2021; Starzyńska and Kuna-Marszałek 2023).

In the Visegrad Group countries, the energy sector is largely based on fossil fuels, although recently, there has been a gradual shift towards renewable energy sources. A key challenge for these countries is the need to make new investments in renewable energy sources, which requires substantial financial outlays. This highlights the importance of ensuring stable financial flows for investments in green technologies in the energy sector (Dorożyński and Kuna-Marszałek 2016; Kochanek 2021; Uğurlu 2022).

To the best of our knowledge, research on the interdependence between ES and SD in the energy sector is rudimentary and incomplete. Therefore, our study contributes to the development of knowledge in this area. This is especially important in the context of the current, dynamically changing geopolitical situation.

Research methodology

The aim of this research was to examine how ES influences the stable development of the energy sector in the Visegrad Group nations (Poland, Slovakia, Hungary, and Czechia) from 2008 to 2020. We analyzed those countries due to their shared political transformation and accession to the European Union at the beginning of the 21st century. Moreover, their energy sectors are based on fossil fuels and require reforms to implement green solutions. The economies of these countries are diverse, characterized by different levels of investment and varying impacts of macroeconomic conditions on energy sector development. Socioeconomic and environmental protection policies are implemented in different ways in each country.

In this context, we formulated the main research hypothesis as follows:

Economic security positively influences the sustainable development of the energy sector, though the magnitude and pathways of this effect vary significantly across the Visegrad countries due to differences in macroeconomic stability, energy policies, and innovation capacity.

The analyses included various elements.

1. We created an index for the E, S, Env, and SD dimensions of the energy sector. The construction of this index involved a number of steps.
2. Collecting analytical indicators and grouping them into the three pillars of SD, including:
   - Economic Dimension (E):
     - Positive indicators: Gross operating surplus (million EUR), investment rate (%), total purchases of goods and services (million EUR), number of companies, gross premiums written (million EUR), production value (million euros), value added at factor cost (million EUR), and gross investment in tangible assets (million EUR).
     - Negative indicator: cost-level index for total activity (%).
   - Social Dimension (S):
     - Positive indicators: Workforce size, expenditure on employee training and courses, social security costs (million EUR), gross value added per employee (thousand EUR), total wages and salaries (million EUR), investment per employee (thousand EUR), employer's social charges as a percentage of total personnel costs (%), and apparent labor productivity.
     - Negative indicators: workplace accident rates, share of personnel costs in total production (%), and total personnel costs (million EUR).
   - Environmental Dimension (Env):
     - Negative indicators: ammonia emissions, hydrofluorocarbons (CO_2 equivalent), methane emissions, sulfur oxides (SO_2 equivalent), carbon monoxide, nitrous oxide, and carbon dioxide.
       a) Transformation of the explanatory variables into integrated variables using the following formulas:

For stimulants:

$$\mathrm{xsnorm}_{ij} = \sum_{i=1}^{n} \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}$$

For destimulants:

$$\mathrm{xdnorm}_{ij} = \sum_{i=1}^{n} \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \quad (1)$$

where:
$xsnorm_{ij}; xdnorm_{ij}$ – standardized value of the j-th in year i;
x_{ij} – diagnostic indicator for year i;

b) Application of the following equation to construct the SD:

$$SD = \left(\frac{1}{nE} \sum_{j=1}^{nE} xnormij + \frac{1}{nS} \sum_{j=1}^{nS} xnormij + \frac{1}{nEnv} \sum_{j=1}^{nEnv} xnormij \right)/3; SD \in \left[0; 1\right], \quad (2)$$

where:
SD_i – aggregated variable for year i.
xnormij – normalized value of the *j*-th diagnostic indicator for country (or year) *i*,
nE, nS, nEnv – number of diagnostic indicators in the economic, social, and environmental dimensions.

3. We created ES indicators based on formula (1). We used the following stimulants: gross domestic pct at market prices, the external balance of goods and services, wages and salaries, GERD bsector of performance, and destimulants, including the unemployment rate and HICP.

4. To assess the strength and direction of the linear relationship between SD and ES, we used Pearson's r, Spearman's rho, Goodman–Kruskal's gamma, and Kendall's tau correlation coefficients.

5. We applied the OLS method to estimate the model, represented by the following equation:

$$SD = \widehat{\beta}_0 + \widehat{\beta}_1 \cdot ES + \varepsilon_i, \quad (3)$$

where:
β_0 – intercept term,
β_1 – the slope;
ε_i – residual for the i-th observation;
i – observation index.

The OLS model was specified as a simple linear regression, without lagged independent variables, as the short time dimension of the panel (2008–2020) did not justify a dynamic specification.

6. We developed a structural equation model and estimated it using the SUR method. Although the SUR model assumes the homogeneity of regressors, it was applied here to capture contemporaneous correlations between the error terms of the sustainability dimensions (economic, social, and environmental). Mutual interdependencies among these dimensions may introduce some degree of endogeneity. While this approach provides useful approximations, it constitutes a limitation of the current study. Future research should consider the application of more advanced estimation techniques, such

as Three-Stage Least Squares (3SLS), Structural Equation Modeling (SEM), or Panel Vector Autoregression (PVAR), to fully address potential endogeneity issues.

$$\begin{cases} E = \widehat{\beta}_0 + \widehat{\beta}_1 ES_i + \widehat{\beta}_2 ES_{(t-1)i} + \widehat{\beta}_3 S + \widehat{\beta}_4 Env + e_i \\ S = \widehat{\beta}_0 + \widehat{\beta}_1 ES_i + \widehat{\beta}_2 ES_{(t-1)i} + \widehat{\beta}_3 E + \widehat{\beta}_4 Env + e_i \\ Env = \widehat{\beta}_0 + \widehat{\beta}_1 ES_i + \widehat{\beta}_2 ES_{(t-1)i} + \widehat{\beta}_3 E + \widehat{\beta}_4 S + e_i \end{cases} \quad (4)$$

Results

The first stage of the study involved calculating synthetic indicators that described the degree of ES and the level of SD in the Visegrad Group countries between 2008 and 2020. Detailed data on the indicators discussed are presented in Table 1. All countries showed a positive trend for both indicators in the studied period, meaning that the policies implemented by energy companies for SD and ES were efficient and effective.

Poland exhibited the highest SD dynamics (SD = 0.0348 time + 0.2063; R^2 = 0.8924) while Hungary showed the lowest (SD = 0.0097 time + 0.4252; R^2 = 0.821). Slovakia recorded the highest average SD level (mean = 0.51; Sd = 0.09), while Czechia and Poland had the lowest (mean = 0.45; Sd = 0.07 in Czechia and Sd = 0.14 in Poland). The maximum level of SD was identified in Poland (0.73 in 2020), and the minimum was in Czechia (0.27 in 2008).

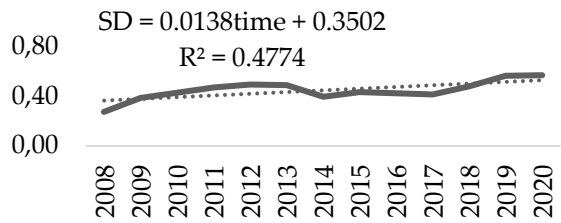
During this period, Poland experienced the highest dynamics of ES (ES = 0.0680 time – 0.0194; R^2 = 0.9576), while Slovakia had the lowest (ES = 0.0585 time + 0.0897; R^2 = 0.9341). Poland demonstrated the highest average ES level (mean = 0.60; Sd = 0.28), while Hungary had the lowest (mean = 0.46; Sd = 0.25). The maximum ES level was identified in Czechia (0.92, 2019), while the minimum level (0.12) was registered in both Poland (in 2009) and Slovakia (in 2008).

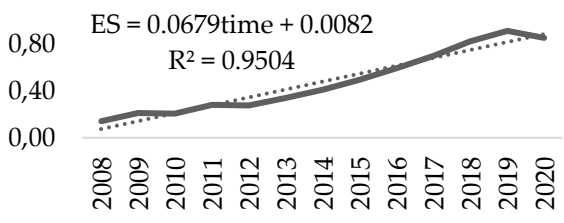
Table 1. The sustainable development and economic security indices of energy companies in the Visegrad Group, 2008–2020

Energy Companies in the Visegrad Group													
Czechia													
Indicator	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
SD	0.27	0.38	0.43	0.47	0.49	0.49	0.40	0.43	0.42	0.41	0.48	0.56	0.57
ES	0.14	0.21	0.21	0.28	0.28	0.34	0.41	0.50	0.60	0.70	0.83	0.92	0.86

Indicator	Descriptive statistics				
	Mean	Sd	Median	Max	Min
SD	0.45	0.07	0.43	0.57	0.27
ES	0.48	0.26	0.41	0.92	0.14

Energy Companies in the Visegrad Group

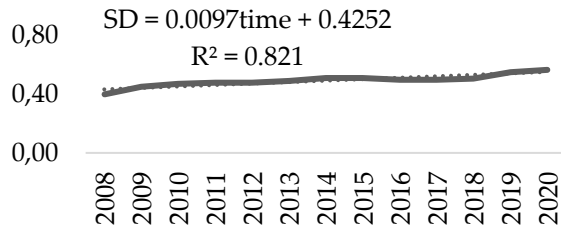


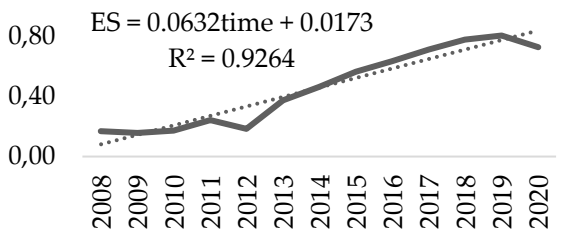


Hungary

Indicator	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
SD	0.40	0.45	0.47	0.48	0.48	0.49	0.51	0.51	0.50	0.50	0.51	0.55	0.57
ES	0.17	0.16	0.17	0.24	0.18	0.37	0.46	0.57	0.63	0.71	0.78	0.80	0.73

Indicator	Descriptive statistics				
	Mean	Sd	Median	Max	Min
SD	0.49	0.04	0.50	0.57	0.40
ES	0.46	0.25	0.46	0.80	0.16

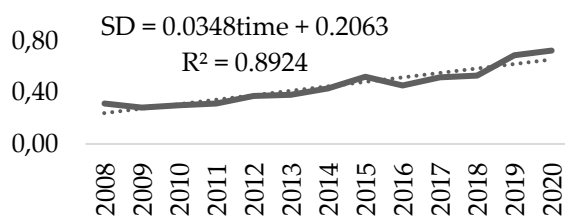


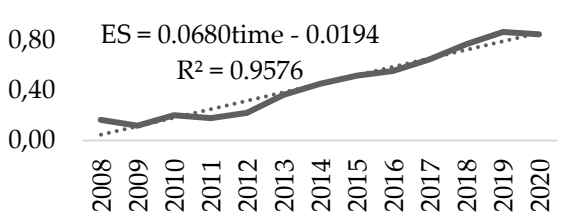


Poland

Indicator	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
SD	0.31	0.28	0.30	0.32	0.37	0.38	0.43	0.52	0.45	0.52	0.53	0.69	0.73
ES	0.16	0.12	0.20	0.18	0.22	0.37	0.45	0.52	0.56	0.65	0.77	0.87	0.85

Indicator	Descriptive statistics				
	Mean	Sd	Median	Max	Min
SD	0.45	0.14	0.43	0.73	0.28
ES	0.60	0.26	0.45	0.87	0.12



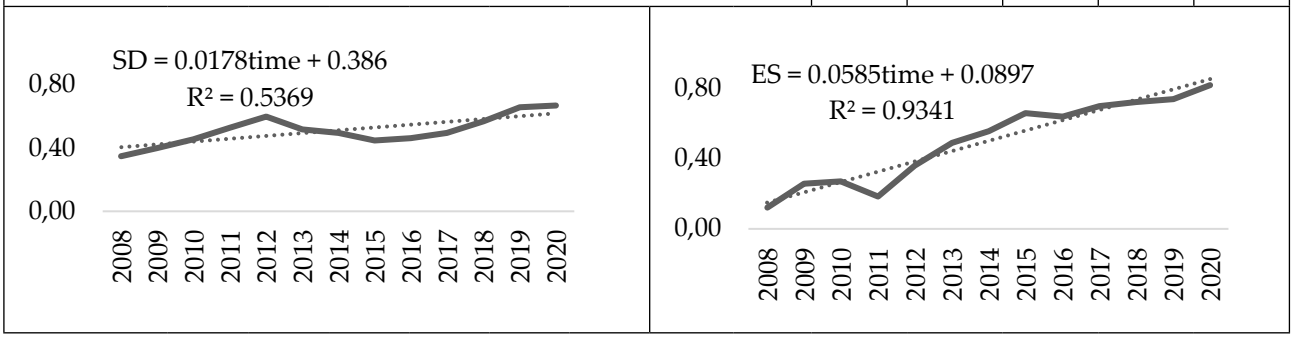


Slovakia

Indicator	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020

Energy Companies in the Visegrad Group													
SD	0.35	0.40	0.45	0.53	0.60	0.52	0.50	0.45	0.46	0.49	0.57	0.66	0.67
ES	0.12	0.26	0.27	0.18	0.36	0.49	0.55	0.66	0.64	0.70	0.72	0.74	0.82

Indicator	Descriptive statistics				
	Mean	Sd	Median	Max	Min
SD	0.51	0.09	0.50	0.67	0.35
ES	0.50	0.23	0.55	0.82	0.12



Source: own study based on Eurostat (n.d.).

Figure 1 presents the Pearson's r correlation coefficients between SD and ES in the Visegrad Group from 2008 to 2020. In all countries, the correlation coefficients between the variables were significant ($p < 0.05$). In all countries, the relationship between SD and ES was positive (the ES indicator of energy companies increased together with their SD indicator). The strength of the correlation coefficients varied across countries. The strongest correlation was observed in Poland (0.96; very strong), while the weakest was recorded in Slovakia (0.60; moderate).

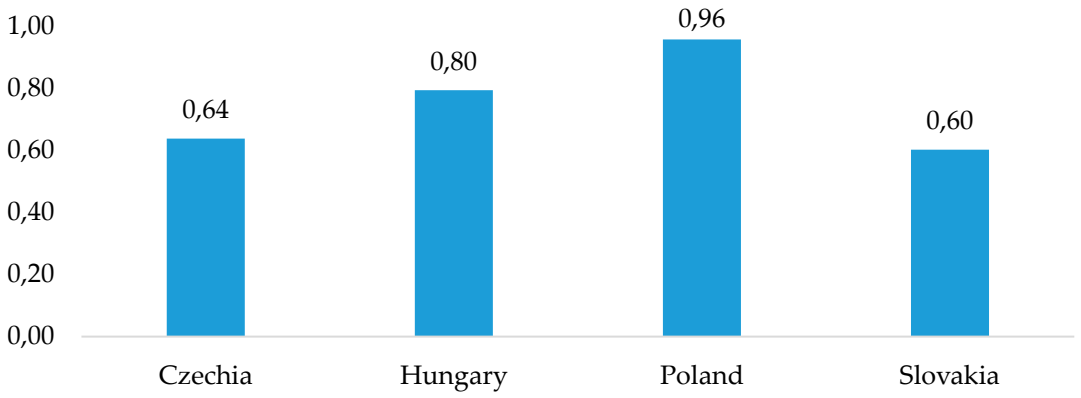


Figure 1. Pearson's correlation coefficients between sustainable development indicators and energy companies' economic security in the Visegrad Group, 2008 to 2020, p <0.05 (n = 13)
Source: own study based on Eurostat n.d.

Table 2 shows the results of OLS regressions that analyze the relationship between SD and ES in the Visegrad Group from 2008 to 2020. The OLS estimations confirmed the absence of collinearity, autocorrelation, heteroskedasticity, and deviations from the normal distribution of variables. They also indicated that ES had a significant impact on SD ($p < 0.05$). The relationship between the variables was positive in all countries but varied in strength. The strongest positive correlation was observed in Poland (0.5091), while the weakest was recorded in Hungary

(0.1302). The coefficient determination ranged from 0.3638 in Slovakia (indicating an unsatisfactory model fit) to 0.9185 in Poland (a very good fit to the model data).

Table 2. The results of the OLS regressions in the Visegrad Group, 2008 to 2020 ($p < 0.05$): $SD = \alpha_0 + \alpha_1 \cdot ES + \varepsilon_i$

Country	Independent variable	Coefficient	Std. error	*p*-value	R2
Czechia	const	0.3582	0.0365	< 0.0001	0.4086
	ES	0.1829	0.0663	0.0187	
Hungary	const	0.4336	0.0156	< 0.0001	0.6320
	ES	0.1302	0.0299	0.0012	
Poland	const	0.2180	0.0240	< 0.0001	0.9185
	ES	0.5091	0.0457	< 0.0001	
Slovakia	const	0.3898	0.0529	< 0.0001	0.3638
	ES	0.2418	0.0964	0.0291	

Source: own study based on Eurostat (n.d.).

Table 3 presents the results of the SUR estimation, which examines the relationships between E, S, Env and ES, E, S, Env (depending on the model specification) in the Visegrad Group from 2008 to 2020. The impact of the examined factors on E, S, and Env varied across countries. In Poland and Slovakia, ES affected all three dimensions. In Czechia, it mainly affected Env, while in Hungary influenced S and Env.

The relationships between the variables were both positive and negative, with varying degrees of strength. The strongest positive relationship was recorded in Slovakia (2.7053, between E and S), while the weakest positive association was observed in Poland (0.1535, between S and ES). Conversely, the most pronounced negative relationship was found in Czechia (2.9984, between Env and S), while the weakest negative relationship was observed in Slovakia (0.1607, between S and ES).

Table 3. Results of the SUR regressions in the Visegrad Group, 2008 to 2020 (p < 0.05):

$$\begin{cases} E = \propto_0 + \propto_1 \cdot ES_i + \propto_2 \cdot S + \propto_3 \cdot Env + \varepsilon_i \\ S = \propto_0 + \propto_1 \cdot ES_i + \propto_2 \cdot E + \propto_3 \cdot Env + \varepsilon_i \\ Env = \propto_0 + \propto_1 \cdot ES_i + \propto_2 \cdot E + \propto_3 \cdot S + \varepsilon_i \end{cases}$$

Country	Dependent variable	Independent variable	Coefficient	Std. error	*p*-value	R2
Czechia	E	const	−0.7816	0.0957	9.82E-06	0.8708
		S	2.3324	0.1688	7.70E-08	
		Env	0.5082	0.0900	0.0002	
	S	const	0.3365	0.0229	4.23E-08	0.8981
		E	0.4269	0.0309	7.70E-08	
		Env	−0.2190	0.0360	0.0001	
	Env	const	1.1296	0.1155	4.31E-06	0.8678
		ES	0.2222	0.0572	0.0037	
		E	1.1513	0.1987	0.0003	
		S	−2.9984	0.4079	4.32E-05	
Hungary	E	const	1.4678	0.1479	1.70E-06	0.7944
		S	−1.5137	0.3073	0.0006	
		Env	−0.6212	0.0728	6.66E-06	
	S	const	0.6301	0.0380	1.32E-08	0.5886
		ES	−0.1905	0.0357	0.0003	
		E	−0.2631	0.0606	0.0015	
	Env	const	0.7761	0.0873	4.63E-06	0.9099
		ES	0.5013	0.0827	0.0001	
		E	−0.8883	0.1396	8.21E-05	
Poland	E	const	0.1262	0.0514	0.0319	0.777
		ES	0.6596	0.0980	3.24E-05	
	S	const	0.3906	0.0137	1.17E-11	0.7265
		ES	0.1535	0.0261	0.0001	
	Env	const	0.1371	0.0487	0.0167	0.8203
		ES	0.7142	0.0987	9.32E-06	

Country	Dependent variable	Independent variable	Coefficient	Std. error	*p*-value	R2
Slovakia	E	const	–1.0550	0.1787	0.0002	0.6983
		ES	0.4080	0.0962	0.0017	
		S	2.7053	0.3064	4.91E-06	
	S	const	0.4050	0.0245	1.37E-08	0.8035
		ES	–0.1607	0.0908	0.0006	
		E	0.3376	0.0379	4.53E-06	
	Env	const	0.1376	0.0607	0.0448	0.8270
		ES	0.8737	0.1108	7.51E-06	

Source: own study based on Eurostat (n.d.).

The coefficient of determination ranged from 0.5886 (in Hungary for S, signifying a weak fit to the model data) to 0.9099 (also in Hungary, but for Env; a very good fit).

Discussion

The development of the sustainable energy sector is a key issue for the Visegrad Group countries, as it is strongly related to national security and constitutes the basis for sustainable socioeconomic development (Silvestre and Ţîrcă 2019; Wang, Chen, and Li 2022; Zhou et al. 2022).

We recorded a positive increase in the Sustainable Development Index and ES in the four countries, which is consistent with Siksnelyte et al. (2018), Kochanek (2021), Misztal, Kowalska, and Fajczak-Kowalska (2022), and Uğurlu (2022). However, this development was marked by slight fluctuations, which can be attributed to negative developments stemming from the financial crisis and the situation in the energy raw material market.

We confirmed the main research hypothesis, as ES demonstrated a statistically significant positive impact on SD in all four countries, although the strength of this influence varied. This variation may have resulted from different policies implemented by the countries, different approaches to environmental protection and renewable energy sources, and the structure and susceptibility to external conditions of each economy (Heffron et al. 2021).

In response to the first research question, the dynamics of the Sustainable Development Index showed a positive trend in all countries. The highest growth was observed in Poland, while the lowest was recorded in Hungary. The SD of the energy sector is particularly crucial for the Polish economy, as the adoption of innovative technologies will help the country achieve ambitious goals and challenges in this area (Cable 1995; Kochanek 2021). Hungary, on the other hand, remains highly dependent on energy imports from Russia, necessitating a comprehensive system of reforms to improve energy security and sustainability.

ES indicators are growing much faster than those for SD. The highest dynamics level was recorded in Czechia and Poland, while the lowest was in Slovakia. It is notable how these countries gradually emerged from the financial crisis through macroeconomic, fiscal, and monetary

policies. The impact of ES on the three pillars of sustainability varied. In Czechia, ES only affected Env. In Hungary, it affected S and Env, while in Poland and Slovakia, it affected E, S, and Env. The results of the SUR estimation indicate that ES is extremely important for SD in Poland and Slovakia, which may suggest that the sector is highly dependent on macroeconomic policy. On the other hand, in Czechia, ES affected only environmental aspects, and there was a large interdependence between the pillars of SD. This may mean that the internal situation in the sector is of vital importance for its SD.

The theoretical implications of this analysis include the development of an original conceptual framework that links ES with sustainable energy development. It contributes to the broader economic and sustainability literature by highlighting the role of macroeconomic stability in fostering green transitions. The findings support existing theories of economic resilience and SD while providing new insights into the specific dynamics within the Visegrad Group countries.

From an empirical perspective, this study comprehensively assesses the interplay between ES and SD, using robust econometric techniques, such as OLS and SUR models. The results validate the importance of macroeconomic indicators in shaping sustainability outcomes, reinforcing the need for data-driven policymaking. Furthermore, empirical evidence can be a reference point for future studies that explore similar relationships in other regions.

These findings have significant practical implications for policymakers, business leaders, and stakeholders in the energy sector. Governments can employ them to design policies that balance ES and environmental goals. Businesses operating in the energy sector can use the results to align their investment strategies with national and regional sustainability priorities. Future research should focus on expanding the scope to include additional economic and social dimensions and offer a more holistic understanding of the sustainability – economic security nexus.

In our research, we used a deliberately selected custom set of indicators for analysis, which may limit the inference process involving the existing interdependencies.

From a theoretical perspective, the study introduces original definitions of SD in the energy sector and ES. Furthermore, it presents a novel approach to the indicator-based assessment of these phenomena and develops impact models that illustrate the relationship between ES and SD. These contributions expand the existing body of knowledge and provide a foundation for further research in this field.

Practical implications may provide support in decision-making in energy sector companies.

Conclusions

The analysis of the Visegrad Group countries confirms that the sustainable development of the energy sector and economic security are closely linked and show positive growth trends. The results indicate that ES has a significant impact on the sustainability of the energy sector, although the strength and direction of this impact vary from country to country. This

differentiation comes from varied national energy policies, the level of investment in renewable energy sources, and macroeconomic conditions.

Poland recorded the highest increase in sustainability indicators, which points to the effectiveness of their economic policies and investments in green energy. Hungary, on the other hand, showed the lowest growth dynamics, which underlines the need for further reforms and diversification of energy sources. Czechia and Slovakia exhibited moderate but stable growth in both SD and ES.

From a macroeconomic perspective, ES factors such as GDP growth, foreign trade balances, and wage levels contribute positively to SD, while higher unemployment rates and inflation exert a negative influence. The SUR estimation results suggest that ES affects all three SD pillars in Poland and Slovakia. In Czechia, it mainly affects ecological aspects, while in Hungary, it impacts social and environmental issues.

The results underscore the importance of coordinated macroeconomic policies to ensure the long-term sustainability of the energy sector. Reinforcing financial stability, supporting investments in renewables, and implementing policies that increase resilience in the labor market are key steps toward energy security and sustainability.

In conclusion, the energy sector in the Visegrad Group countries is undergoing a positive transformation towards sustainable development. However, to reduce existing disparities and accelerate the transition towards a greener and safer energy future, targeted policies, strategic investments, and innovation-based reforms are needed.

References

Ahmad, U.S., Usman, M., Hussain, S., Jahanger, A., Abrar, M. (2022), *Determinants of renewable energy sources in Pakistan: An overview*, "Environmental Science and Pollution Research", 29 (19), pp. 29183–29201, https://doi.org/10.1007/s11356-022-18502-w

Akimov, O., Troschinsky, V., Karpa, M., Ventsel, V., Akimova, L. (2020), *International experience of public administration in the area of national security*, "Journal of Legal, Ethical and Regulatory Issues", 23 (1), http://ep3.nuwm.edu.ua/id/eprint/18288 (accessed: 5.02.2025).

Alper, A., Oguz, O. (2016), *The role of renewable energy consumption in economic growth: Evidence from asymmetric causality*, "Renewable and Sustainable Energy Reviews", 60, pp. 953–959, https://doi.org/10.1016/j.rser.2016.01.123

Armstrong, S., Urata, S. (2023), *'Japan First'? Economic security in a world of uncertainty*, "Navigating Prosperity and Security in East Asia", pp. 87–118, https://doi.org/10.22459/NPSEA.2023.05

Bogołębska, J., Feder-Sempach, E., Stawasz-Grabowska, E. (2019), *Reserve Currency Status as a Safe Asset Determinant. Empirical Evidence from Main Public Issuers in the Period 2005–2017*, "Comparative Economic Research. Central and Eastern Europe", 22 (3), pp. 65–81, http://doi.org/10.2478/cer-2019-0023

Bose, S., Khan, H.Z. (2022), *Sustainable development goals (SDGs) reporting and the role of country-level institutional factors: An international evidence*, "Journal of Cleaner Production", 335, 130290, https://doi.org/10.1016/j.jclepro.2021.130290

Cable, V. (1995), *What is international economic security?*, "International Affairs", 71 (2), pp. 305–324, https://doi.org/10.2307/2623436

Cergibozan, R. (2022), *Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries*, "Renewable Energy", 183, pp. 617–626, https://doi.org/10.1016/j.renene.2021.11.056

Colbert, B.A., Kurucz, E.C. (2007), *Three conceptions of triple bottom line business sustainability and the role for HRM*, "Human Resource Planning", 30 (1), pp. 21–29.

Dorożyński, T., Kuna-Marszałek, A. (2016), *Investments Attractiveness: The Case of the Visegrad Group Countries*, "Comparative Economic Research, Central and Eastern Europe", 19 (1), pp. 119–140, http://doi.org/10.1515/cer-2016-0007

Dźwigoł, H., Dźwigoł-Barosz, M., Zhyvko, Z., Miśkiewicz, R., Pushak, H. (2019), *Evaluation of the energy security as a component of national security of the country*, "Journal of Security & Sustainability Issues", 8 (3), pp. 307–317, https://www.researchgate.net/profile/Zinaida-Zhyvko/publication/332003487_Evaluation_of_the_energy_security_as_a_component_of_national_security_of_the_country/links/5d93183892851c33e94b4e7c/Evaluation-of-the-energy-security-as-a-component-of-national-security-of-the-country.pdf (accessed: 5.02.2025).

Giovannoni, E., Fabietti, G. (2013), *What is Sustainability? A Review of the Concept and its Applications*, [in:] C. Busco, M.L. Frigo, A. Riccaboni, P. Quattrone (eds.), *Integrated Reporting. Concepts and Cases that Redefine Corporate Accountability*, Springer, Cham–Heidelberg–New York–Dordrecht–London, pp. 21–40, https://doi.org/10.1007/978-3-319-02168-3_2

Gong, X. (2022), *Energy security through a financial lens: Rethinking geopolitics, strategic investment, and governance in China's global energy expansion*, "Energy Research & Social Science", 83, 102341, https://doi.org/10.1016/j.erss.2021.102341

Halkos, G.E., Gkampoura, E.C. (2020), *Reviewing Usage, Potentials, and Limitations of Renewable Energy Sources*, "Energies", 13 (11), 2906, https://doi.org/10.3390/en13112906

Heffron, R.J., Körner, M.F., Schöpf, M., Wagner, J., Weibelzahl, M. (2021), *The role of flexibility in the light of the COVID-19 pandemic and beyond: Contribution to a sustainable and resilient energy future in Europe*, "Renewable and Sustainable Energy Reviews", 140, 110743, https://doi.org/10.1016/j.rser.2021.110743

Hobela, V., Melnyk, S. (2021), *Offshoring as a Threat to the National Economic Security: Causes and Ways to Counteract*, "Scientific Bulletin of Mukachevo State University. Series "Economics", 8 (2), pp. 9–16, https://doi.org/10.52566/msu-econ.8(2).2021.9-16

Hosseini, S.E. (2020), *An outlook on the global development of renewable and sustainable energy at the time of COVID-19*, "Energy Research & Social Science", 68, 101633, https://doi.org/10.1016/j.erss.2020.101633

Kamran, M., Fazal, M.R., Mudassar, M. (2020), *Towards empowerment of the renewable energy sector in Pakistan for sustainable energy evolution: SWOT analysis*, "Renewable Energy", 146, pp. 543–558, https://doi.org/10.1016/j.renene.2019.06.165

Khan, K., Khurshid, A., Cifuentes-Faura, J. (2023), *Investigating the relationship between geopolitical risks and economic security: Empirical evidence from central and Eastern European countries*, "Resources Policy", 85, 103872, https://doi.org/10.1016/j.resourpol.2023.103872

Kochanek, E. (2021), *The Energy Transition in the Visegrad Group Countries*, "Energies", 14 (8), 2212, https://doi.org/10.3390/en14082212

Komarnicka, A., Murawska, A., (2021), *Comparison of Consumption and Renewable Sources of Energy in European Union Countries – Sectoral Indicators, Economic Conditions and Environmental Impacts*, "Energies", 14 (12), 3714, https://doi.org/10.3390/en14123714

Koval, V., Duginets, G., Plekhanova, O., Antonov, A., Petrova, M. (2019), *On the supranational and national level of global value chain management*, "Entrepreneurship and Sustainability Issues", 6 (4), pp. 1922–1937, https://doi.org/10.9770/jesi.2019.6.4(27)

Kuzma, E., Sehnem, S. (2022), *Proposition of a structural model for business value creation based on circular business models, innovation, and resource recovery in the pet industry, "Business Strategy and the Environment"*, 32 (1), pp. 516–537, https://doi.org/10.1002/bse.3158

Lee, C.C., Xing, W., Lee, C.C. (2022), *The impact of energy security on income inequality: The key role of economic development*, "Energy", 248, 123564, https://doi.org/10.1016/j.energy.2022.123564

Likhonosova, G., Aleksejeva, L., Zieiniiev, T., Shalbayeva, S. (2023), *Approaches to ensuring the economic security of the relocated business*, "Access to Science, Business, Innovation in Digital Economy", 4 (1), pp. 115–129, https://doi.org/10.46656/access.2023.4.1(9)

Lu, J., Ren, L., Yao, S., Qiao, J., Strielkowski, W., Streimikis, J. (2019), *Comparative Review of Corporate Social Responsibility of Energy Utilities and Sustainable Energy Development Trends in the Baltic States*, "Energies", 12 (18), 3417, https://doi.org/10.3390/en12183417

Marra, A., Colantonio, E. (2022), *The institutional and socio-technical determinants of renewable energy production in the EU: implications for policy*, "Journal of Industrial and Business Economics", 49 (2), pp. 267–299, https://doi.org/10.1007/s40812-022-00212-6

Misztal, A., Kowalska, M., Fajczak-Kowalska, A. (2022), *The Impact of Economic Factors on the Sustainable Development of Energy Enterprises: The Case of Bulgaria, Czechia, Estonia and Poland*, "Energies", 15 (18), 6842, https://doi.org/10.3390/en15186842

Pieloch-Babiarz, A., Misztal, A., Kowalska, M. (2021), *An impact of macroeconomic stabilization on the sustainable development of manufacturing enterprises: the case of Central and Eastern European Countries*, "Environment, Development and Sustainability", 23 (6), pp. 8669–8698, https://doi.org/10.1007/s10668-020-00988-4

Porter, M.E., Kramer, M.R. (2007), *Strategy and society, the link between competitive advantage and corporate social responsibility*, "Harvard Business Review", 84 (12), pp. 78–92.

Prasad, S., Sheetal, K.R., Venkatramanan, V., Kumar, S., Kannojia, S. (2019), *Sustainable Energy: Challenges and Perspectives* [in:] S. Shah, V. Venkatramanan, R. Prasad (eds.), *Sustainable Green Technologies for Environmental Management*, Springer, Singapore, pp. 175–197, https://doi.org/10.1007/978-981-13-2772-8_9

Razmjoo, A., Kaigutha, L.G., Rad, M.V., Marzband, M., Davarpanah, A., Denai, M.J.R.E. (2021), *A technical analysis investigating energy sustainability utilizing reliable renewable energy sources to reduce CO2 emissions in a high potential area*, "Renewable Energy", 164, pp. 46–57, https://doi.org/10.1016/j.renene.2020.09.042

Sebestyén, V. (2021), *Renewable and Sustainable Energy Reviews: Environmental impact networks of renewable energy power plants*, "Renewable and Sustainable Energy Reviews", 151, 111626, https://doi.org/10.1016/j.rser.2021.111626

Siksnelyte, I., Zavadskas, E.K., Streimikiene, D., Sharma, D. (2018), *An Overview of Multi-Criteria Decision-Making Methods in Dealing with Sustainable Energy Development Issues*, "Energies", 11 (10), 2754, https://doi.org/10.3390/en11102754

Silvestre, B.S., Ţîrcă, D.M. (2019), *Innovations for sustainable development: Moving toward a sustainable future*, "Journal of Cleaner Production", 208, pp. 325–332, https://doi.org/10.1016/j.jclepro.2018.09.244

Starzyńska, D., Kuna-Marszałek, A. (2023), *Development of Renewable Energy in View of Energy Security – The Study of the Photovoltaic Market in Poland*, "Energies", 16 (19), 6992, https://doi.org/10.3390/en16196992

Stern, D.I. (2011), *The role of energy in economic growth*, "Annals of the New York Academy of Sciences", 1219 (1), pp. 26–51, https://doi.org/10.1111/j.1749-6632.2010.05921.x

Štreimikienė, D., Samusevych, Y., Bilan, Y., Vysochyna, A., Sergi, B.S. (2022), *Multiplexing efficiency of environmental taxes in ensuring environmental, energy, and economic security*, "Environmental Science and Pollution Research", 29, pp. 7917–7935, https://doi.org/10.1007/s11356-021-16239-6

Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., O'Regan, N., Rozenberg, J., Watkins, G., Hall, J.W. (2019), *Infrastructure for sustainable development*, "Nature Sustainability", 2 (4), pp. 324–331, https://doi.org/10.1038/s41893-019-0256-8

Uğurlu, E. (2022), *Impacts of Renewable Energy on CO2 Emission: Evidence from the Visegrad Group Countries*, "Politics in Central Europe", 18 (2), pp. 295–315, https://doi.org/10.2478/pce-2022-0013

Valentine, S.V. (2011), *Emerging symbiosis: Renewable energy and energy security*, "Renewable and Sustainable Energy Reviews", 15 (9), pp. 4572–4578, https://doi.org/10.1016/j.rser.2011.07.095

Wahab, S., Zhang, X., Safi, A., Wahab, Z., Amin, M. (2021), *Does Energy Productivity and Technological Innovation Limit Trade-Adjusted Carbon Emissions?*, "Economic Research – Ekonomska Istraživanja", 34 (1), pp. 1896–1912, https://doi.org/10.1080/1331677X.2020.1860111 https://doi.org/10.1016/10.1080/1331677X.2020.1860111

Wang, L., Chen, L., Li, Y. (2022), *Digital economy and urban low-carbon sustainable development: the role of innovation factor mobility in China*, "Environmental Science and Pollution Research", 29 (32), pp. 48539–48557, https://doi.org/10.1007/s11356-022-19182-2

Zahoor, Z., Khan, I., Hou, F. (2022), *Clean energy investment and financial development as determinants of environment and sustainable economic growth: evidence from China*, "Environmental Science and Pollution Research", 29, pp. 16006–16016, https://doi.org/10.1007/s11356-021-16832-9

Zhou, Z., Liu, W., Cheng, P., Li, Z. (2022), *The Impact of the Digital Economy on Enterprise Sustainable Development and Its Spatial-Temporal Evolution: An Empirical Analysis Based on Urban Panel Data in China*, "Sustainability", 14 (19), 11948, https://doi.org/10.3390/su141911948

Bezpieczeństwo energetyczne i zrównoważony rozwój sektora energetycznego – analiza na przykładzie krajów Grupy Wyszehradzkiej

Zrównoważony rozwój sektora energetycznego ma kluczowe znaczenie dla stabilnego i zrównoważonego rozwoju społeczno-ekonomicznego kraju, w harmonii z ochroną środowiska naturalnego. Jednym z czynników wpływających na jego poziom jest bezpieczeństwo ekonomiczne, które jest podstawą funkcjonowania państwa. Głównym celem artykułu jest ocena wpływu bezpieczeństwa ekonomicznego na zrównoważony rozwój sektora energetycznego w krajach Grupy Wyszehradzkiej, czyli w Czechach, na Węgrzech, w Polsce i na Słowacji, w latach 2008–2020. Aby ocenić statystycznie istotną zależność między wskaźnikami ($p < 0,05$), wykorzystano współczynniki korelacji, metodę najmniejszych kwadratów oraz model SUR. Wyniki badań wskazują, że bezpieczeństwo ekonomiczne ma wpływ na zrównoważony rozwój sektora energetycznego. Zaleca się koordynację polityki makroekonomicznej w celu osiągnięcia pozytywnych rezultatów w sektorze energetycznym. Energia odnawialna i zielone źródła energii mogą odegrać tutaj kluczową rolę.

Słowa kluczowe: sektor energetyczny, zrównoważony rozwój, bezpieczeństwo ekonomiczne

Comparative Economic Research. Central and Eastern Europe
Volume 29 Number 1, 2026
https://doi.org/10.18778/1508-2008.29.03

Digital Transformation Success in the UAE: The Impact of Leadership, Organizational Flexibility, and Strategic Planning Based on Structural Equation Modeling

Fadi Sakka https://orcid.org/0009-0005-5854-2755
Ph.D., Department of Business, HR Mark, Dubai, UAE, e-mail: fadi.sakka@gmail.com; fadisakka@alibagl.com

Abstract

This study explores the relationship between leadership, organizational flexibility, and strategic planning, and the power of these elements to promote successful digital transformation in the context of the United Arab Emirates. This quantitative study involves the use of surveys and questionnaires that were distributed to 1000 mid-to-senior-level managers. Data on 600 valid answers (representing a response rate of 60%) were analyzed with Structural Equation Modelling (SEM) using AMOS software. The research examines three primary concepts: Leadership, Organizational Flexibility, and Strategic Planning, and how they influence the achievement of Successful Digital Transformation. The findings reveal that 82% of participants said that visionary leadership is essential for digital transformation, 78% stressed the need to effectively communicate goals, and 81% emphasized motivating employees. Furthermore, 75% of the participants said that their businesses had the capacity to adjust to changes, while 73% acknowledged the presence of flexible work practices, and 80% emphasized the need for cross-functional cooperation. Of the 77% of respondents who stated that their firms have a clearly defined digital strategy, 79% had aligned their digital strategy with their company goals, and 74% had included quantifiable targets and key performance indicators (KPIs). These results emphasize the significance of integrating artificial intelligence and data analytics with effective human leadership and strategic planning. It is suggested that organizations enhance their leadership capabilities, foster a flexible culture, and develop comprehensive digital strategies to reap the benefits of digital transformation to the maximum.

Keywords: artificial intelligence, digital transformation, leadership, strategic planning, structural equation modelling

JEL: O32

Funding information: Department of Business, HR Mark, Dubai, UAE.
Declaration regarding the use of GAI tools: Not used.
Conflicts of interests: None.
Ethical considerations: The Author assures of no violations of publication ethics and takes full responsibility for the content of the publication.
Received: 25.06.2025. Verified: 22.08.2025. Accepted: 29.01.2026

Introduction

In the United Arab Emirates (UAE), digital transformation plays a vital role in promoting innovation and competitiveness, supported by initiatives such as Smart Dubai and the UAE AI Strategy 2031. By incorporating artificial intelligence (AI) and data analytics into their business processes, companies can streamline their decision-making, speed up processes, and improve consumer experiences (Kanungo, Liu, and Gupta 2024). The primary objective of this study is to examine the impact of leadership, organizational flexibility, and strategic planning on the success of digital transformation initiatives within organizations operating in the UAE.

AI and data analytics have brought about a significant transformation in several industries. With the help of AI algorithms, it is possible to analyze and process large amounts of data and obtain useful information that can improve the accuracy of predictions and decisions. One such example is predictive analytics, which can forecast the behavior of customers so that organizations can tailor their marketing campaigns to them precisely. It also improves operational efficiency by automating repetitive tasks provided by AI-driven automation and enabling human resources to engage in more significant activities (Fadani 2023; Lada et al. 2023; Basole, Park, and Seuss 2024).

While technological innovations such as AI and data analytics provide the foundation for digital transformation, managerial factors like leadership, organizational flexibility, and strategic planning are critical to its success in the UAE. Effective digital transformation requires the essential qualities of leadership, creativity, and emotional intelligence. Leaders must possess the ability to effectively articulate their vision, motivate their staff, and cultivate an environment that encourages creativity and ongoing education. It is crucial to provide employees with the authority and resources to effectively adjust to emerging technology and make well-informed choices (Beushe et al. 2024; Madanchian et al. 2024; Tursunbayeva and Gal 2024).

The UAE is a notable exemplar of digital transformation. The government has developed extensive digital policies with the goal of establishing the nation as a worldwide leader in innovation and technology. The nation's commitment to using digital technology to improve public services and stimulate economic development is shown by key programs such as Smart Dubai, Smart Abu Dhabi, and the UAE Artificial Intelligence Strategy 2031 (Al Jabri et al. 2024; Almazrouei et al. 2024). The results of research on Abu Dhabi, the United Arab Emirates and in the United states showed that: 1) During a systematic healthcare crisis such as the COVID-19 pandemic, flexible CIO leadership involved exploiting IT resources, as well as exploring and innovating to build IT resiliency; 2) Building IT resiliency for future crisis focuses on four inter-related capabilities: flexible leadership, governance, innovation and learning, and HIT infrastructure (Cousins et al. 2023).

To provide context for the UAE's digital transformation efforts, Table 1 presents a descriptive comparison of digital transformation initiatives in the UAE, the United States, and Singapore, drawing on the existing literature (Nadeem et al. 2024).

Table 1. Comparison of Digital Transformation Initiatives in the UAE, USA, and Singapore

Aspect	UAE	United States	Singapore
Government Strategy	UAE AI Strategy 2031, Smart Dubai, Smart Abu Dhabi	National AI Initiative	Smart Nation Initiative
Key Technologies	AI, Blockchain, IoT	AI, Big Data, Cloud Computing	AI, IoT, Smart City Technologies
Focus Areas	Public Services, Health, Transportation, Energy	Defense, Healthcare, Transportation, Agriculture	Public Services, Healthcare, Urban Development
Major Achievements	Paperless government, Blockchain-powered services	Leading AI research, Advanced healthcare technologies	Comprehensive smart city infrastructure, AI in public services
Challenges	Integration of diverse technologies, Cybersecurity	Ethical concerns, Data privacy, Regulation	Data privacy, Cybersecurity, Talent acquisition
Future Goals	Global AI leadership, Enhanced public services	Maintain AI leadership, Address ethical AI concerns	AI-driven economy, Sustainable urban living

Source: author's elaboration.

Achieving a competitive advantage in the UAE has become essential in light of the ongoing digital transformation, which is shaped by managerial variables, including leadership, organizational flexibility, and strategic planning, as well as technological advancements, including AI and data analytics. The UAE's proactive and strategic approach to digital transformation serves as a model for other governments and businesses. The country demonstrates how to effectively navigate and thrive in the digital era by combining cutting-edge technology with human expertise and promoting a culture of innovation.

Despite the growing body of literature on digital transformation, most studies primarily emphasize technological drivers or focus on Western contexts (Bharadwaj et al. 2013; Chanias, Myers, and Hess 2019; Nadeem et al. 2024). There is a lack of research exploring how leadership, organizational flexibility, and strategic planning interact to influence the success of digital transformation in the UAE. By addressing this gap, the present study contributes to the literature by examining these organizational enablers in the context of an emerging economy. To achieve this, the study formulates three research questions concerning the influence of leadership, organizational flexibility, and strategic planning on digital transformation outcomes in UAE organizations, and develops corresponding hypotheses to empirically test these relationships.

The study addresses three specific research questions:

To what extent does Leadership (L) influence Successful Digital Transformation (SDT) in UAE organizations?

1. To what extent does Organizational Flexibility (OF) influence Successful Digital Transformation (SDT) in UAE organizations?
2. To what extent does Strategic Planning (SP) influence Successful Digital Transformation (SDT) in UAE organizations?

Based on the research questions, the following hypotheses are proposed:

1. Leadership (L) has a positive and significant effect on Successful Digital Transformation (SDT).
2. Organizational Flexibility (OF) has a positive and significant effect on Successful Digital Transformation (SDT).
3. Strategic Planning (SP) has a positive and significant effect on Successful Digital Transformation (SDT).

The contribution of this study is twofold. Theoretically, it extends the literature by highlighting the organizational enablers of digital transformation in a non-Western, emerging economy context. Practically, it provides managers and policymakers in the UAE with actionable insights into how leadership, flexibility, and strategic planning can be exploited to enhance digital transformation initiatives.

Literature review

Digital transformation can be viewed as the adoption of digital technology in every aspect of a firm, which leads to an expansive change in the way companies do business and create value for their consumers. This transformation touches upon a broad spectrum of processes, including AI, data analysis, as well as the automation of processes. Its major goal is to guarantee operational efficiency, enhance the client experience, and foster innovation.

The digital transformation is based on three important concepts: innovation theory, resource-based view (RBV) theory, and dynamic capabilities. According to innovation theory, organizational change happens due to technical advancement, which enables the implementation of new business models. RBV theory hypothesizes that firms can achieve long-term competitive advantage through the efficient utilization of unique resources and capabilities, including digital assets and data analytics. Expanding on this concept, the dynamic capabilities framework focuses on the capacity of organizations to effectively combine, develop, and adapt their internal and external skills and abilities (Ahn, Kim, and Lee 2022; Ozdemir et al. 2023).

AI and data analytics provide the technological context for digital transformation, within which managerial factors such as leadership, organizational flexibility, and strategic planning drive success, particularly in the UAE. Davenport and Ronanki (2018) categorize AI technology into three primary groups: process automation, cognitive insight, and cognitive engagement. Process automation is the use of robotic process automation (RPA) to execute repetitive activities. Cognitive insight employs machine learning to identify data trends. Cognitive engagement includes the application of natural language processing and chatbots to communicate with clients. Predictive analytics helps organizations predict future trends and behavior and make a decision before they occur (Shao et al. 2022).

An example of a machine learning algorithm is the one used by Amazon to predict customer preferences and recommend products based on this information, significantly enhancing the customer experience. Netflix uses predictive analytics to enhance viewer engagement and happiness

by suggesting series and movies to viewers based on their watching history. Businesses extensively utilize AI-driven automation systems to improve their operations. For example, IBM's Watson has been used to enhance supply chain management by accurately forecasting potential interruptions and providing recommendations for necessary corrective measures (Bertsimas and Kallus 2020). General Electric (GE) employs AI in its production processes to forecast equipment malfunctions in advance, therefore minimizing operational interruptions and lowering maintenance expenses.

AI-driven chatbots and virtual assistants enhance customer support by delivering immediate, tailored replies. H&M employs AI chatbots to aid clients in product searches and provide suggestions, resulting in increased customer satisfaction (Jiang et al. 2022). Bank of America's Erica, an AI-powered virtual assistant, assists clients with a range of financial operations, improving their entire banking experience.

Technology is an essential element of digital transformation, but people skills are as important. Leadership, which encompasses visionary thinking and the ability to motivate employees, is critical for successfully navigating digital transformation in the UAE, while other human factors, such as creativity and emotional intelligence, complement this process. Leaders must demonstrate a distinct vision and the capacity to motivate their staff to adopt new technology and procedures (Westerman et al. 2012; Tagscherer and Carbon 2023).

A digital transformation requires transformational leadership to bring change and shape an innovation culture. Leaders should be able to communicate the benefits of the digital projects and make people adopt new ways of working. This can be evidenced by Satya Nadella, the Chief Executive Officer of Microsoft, who was able to transform the culture of the company into a more flexible and innovative one that saw Microsoft successfully transition into cloud computing and AI services.

Creative thinking skills are necessary in the context of identifying new ways of using digital technology and developing new business models. There should be a culture of experimentation and risk-taking that organizations should encourage. The 20% philosophy has led to the creation of popular products like Gmail and Google News as the workers at Google are given 20% of their time to come up with products of their own interest.

Emotional intelligence empowers leaders and people to effectively handle the emotional and interpersonal difficulties that arise from digital change. Emotional intelligence encompasses the comprehension and control of one's own emotions, as well as the emotions of others, with the aim of cultivating robust connections and promoting cooperation. Managing opposition to change and ensuring a seamless transition throughout digital transformation efforts are of paramount importance.

The UAE has established itself as a global leader in digital transformation. This achievement can be attributed to the forward-thinking efforts of the government and its strategic investments in technology. The country's experience offers useful insights into the effective execution of digital transformation plans. The Smart Dubai program, which was initiated in 2014, has the objective of converting Dubai into the most intelligent and content-rich city globally. This effort utilizes cutting-edge technologies like AI, blockchain, and the Internet of Things (IoT)

to improve the quality of life for both inhabitants and tourists. The UAE's dedication to digital innovation is shown by initiatives like the Dubai Paperless Strategy, which seeks to eradicate the use of paper in government transactions.

The Happiness Agenda of Smart Dubai uses data analytics to quantify and improve the level of happiness among its residents, showcasing a citizen-focused strategy for digital transformation. The objective of the UAE AI Strategy 2031 is to establish the UAE as a prominent figure in the field of AI on a worldwide scale by 2031. The policy prioritizes the incorporation of AI into nine crucial areas, including transportation, health, and education. Initiatives include the creation of AI research institutes and the advancement of government services driven by AI. This policy has resulted in the establishment of the world's first AI minister, whose responsibility is to supervise AI programs and promote a national environment that is conducive to AI innovation.

The Dubai Blockchain Strategy, launched in 2016, initially aimed to transform Dubai into the world's first city fully powered by blockchain technology by 2020. Since the original target year has passed, the initiative has evolved into broader national digital programs, and blockchain implementation now continues under the UAE Blockchain Strategy 2021–2031 and Dubai's updated Digital Strategy. The plan prioritizes the optimization of government operations, the establishment of new industries, and the attainment of global leadership. The utilization of blockchain technology aims to increase transparency, reduce expenses, and boost the efficacy of government services. As an example, the Dubai Land Department uses blockchain technology to oversee property transactions, thereby reducing the need for paperwork and improving the security and transparency of these transactions.

Although there have been notable advancements, the digital transformation process presents several obstacles, such as cybersecurity threats, safeguarding data privacy, and acquiring skilled personnel. To maintain its position as a digital pioneer, the UAE, like several other countries, must effectively address and overcome these issues.

With the growing dependence of enterprises on digital technology, the risks associated with cybersecurity become more prominent. The UAE has also invested heavily in advanced cybersecurity systems to protect its digital infrastructure and ensure the authenticity and reliability of its digital services (al-Mutawa 2020). The use of the Dubai Cyber Security Strategy proves the proactive attitude of the UAE to the security of its digital resources.

The task of striking a balance between the advantages of data analytics and the need to safeguard personal privacy is a crucial one. The UAE has come up with strict data privacy laws to safeguard individual data besides encouraging data-driven innovations. The Dubai Data Law, which governs the distribution and sharing of data, emphasizes the UAE's commitment to ensuring data privacy.

Ensuring the acquisition and retention of proficient experts in the fields of AI, data analytics, and cybersecurity is crucial for maintaining the continuity of digital transformation. The UAE has prioritized the cultivation of a skilled workforce via educational and training programs, alongside efforts to recruit global knowledge. The UAE AI Camp and similar initiatives have

the objective of educating and motivating young Emiratis to follow professional paths in the fields of AI and technology.

To remain competitive and promote innovation during the digital era, organizations must be ready to undergo digital transformation, which is driven by AI and data analytics. The human aspect, which encompasses attributes such as leadership, creativity, and emotional intelligence, is essential in successfully addressing the complexities of digital transformation. The UAE's proactive and dliberate approach to digital transformation serves as an example to other nations, emphasizing government sponsorship, cooperation between the state and the business sectors, and a focus on education and sustainability. The UAE is on course towards a great digital transformation by addressing the challenge of cybersecurity, data privacy, and talent acquisition. This development is helping make the UAE a global leader in innovation and technology.

Methodology

The research employs quantitative research methodology, involving questionnaires and surveys to collect data from business executives and experts across various sectors. Purposive sampling was used to recruit the respondents, and the sample was narrowed down to mid-to-senior-level managers who actively participated in the digital transformation efforts in their organization. An online survey collected the information from a sample of 1,000 professionals, yielding 600 valid responses–a response rate of 60%. The final sample comprised 600 respondents, of whom 58% were males and 42% females. The age distribution was 45% 35–44, 32% aged 25–34, 18% aged 45–54, and 5% over 55. Regarding education, 62% had a Master's degree, 28% had a Bachelor's degree, and 10% had a Doctorate. The participants represented various industries: 30% IT, 22% finance, 18% healthcare, 15% manufacturing, and 15% other sectors. Over half (55%) had more than ten years of professional experience.

The survey questionnaire was structured into five sections: (1) demographic information, (2) leadership qualities, (3) organizational flexibility, (4) strategic planning, and (5) successful digital transformation. Each construct was measured with 8–10 items rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree).

The data obtained were analyzed using Structural Equation Modeling (SEM) in the AMOS program. SEM was chosen because it is capable of evaluating complex relationships among observable and latent variables. The model includes three main constructs, Leadership (L), Organizational Flexibility (OF) and Strategic Planning (SP), and how they impact Successful Digital Transformation (SDT) (Figure 1).

Figure 1. How leadership, organizational flexibility, and strategic planning impact the successful digital transformation.
Source: author's elaboration.

Each construct was measured using multiple indicators based on survey items. Leadership (L), Organizational Flexibility (OF), Strategic Planning (SP), and Successful Digital Transformation (SDT) were treated as latent constructs, each represented by multiple survey indicators. The measurement model specifies how the latent variables are indicated by their respective observed variables, each rated on a 5-point Likert scale.

Leadership (L):

- L → L1, L2, L3, L4, L5, L6, L7, L8, L9, L10

Organizational Flexibility (OF):

- OF → OF1, OF2, OF3, OF4, OF5, OF6, OF7, OF8, OF9, OF10

Strategic Planning (SP):

- SP → SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, SP9, SP10

Successful Digital Transformation (SDT):

- SDT → SDT1, SDT2, SDT3, SDT4, SDT5, SDT6, SDT7, SDT8, SDT9, SDT10

The structural model tests the hypothesized relationships among the latent variables modeling the influence of Leadership (L), Organizational Flexibility (OF), and Strategic Planning (SP) on Successful Digital Transformation (SDT) within a single multivariate structural equation model as follows:

$$SDT = \alpha + \beta_1 L + \beta_2 OF + \beta_3 SP + \epsilon,$$

where α is the intercept, β_1, β_2, and β_3 are standardized path coefficients for Leadership, Organizational Flexibility, and Strategic Planning, respectively, and ϵ is the error term.

The model validation involves assessing construct reliability and validity, as well as the overall fit of the model. Construct reliability was assessed using Cronbach's alpha and composite reliability (CR) values. Acceptable thresholds are:

- Cronbach's alpha > 0.70,
- Composite reliability (CR) > 0.70.

Convergent validity was assessed by calculating the Average Variance Extracted (AVE). A convergent validity is considered satisfactory if the AVE value is more than 0.50. Discriminant validity was established by ensuring that the square root of the AVE for each construct exceeded its correlations with other constructs.

Model fit was evaluated using multiple indices:

1. The chi-square (χ^2) statistic: Smaller values suggest a better fit; a p-value > 0.05 indicates a lack of statistical significance, which shows that the data fits well. However, due to the influence of sample size, additional measures are also considered.
2. The Root Mean Square Error of Approximation (RMSEA): Values below 0.06 indicate a good fit.
3. The Comparative match Index (CFI): Values above 0.95 indicate a good fit.
4. The Tucker-Lewis Index (TLI): Values above 0.95 indicate a good fit.

Results

The SEM analysis was conducted using AMOS software, focusing on the constructs of Leadership (L), Organizational Flexibility (OF), Strategic Planning (SP), and Successful Digital Transformation (SDT). Figure 2 shows a Structural Equation Model (SEM) diagram, while Table 2 provides the means and standard deviations for the observed variables used to measure each construct.

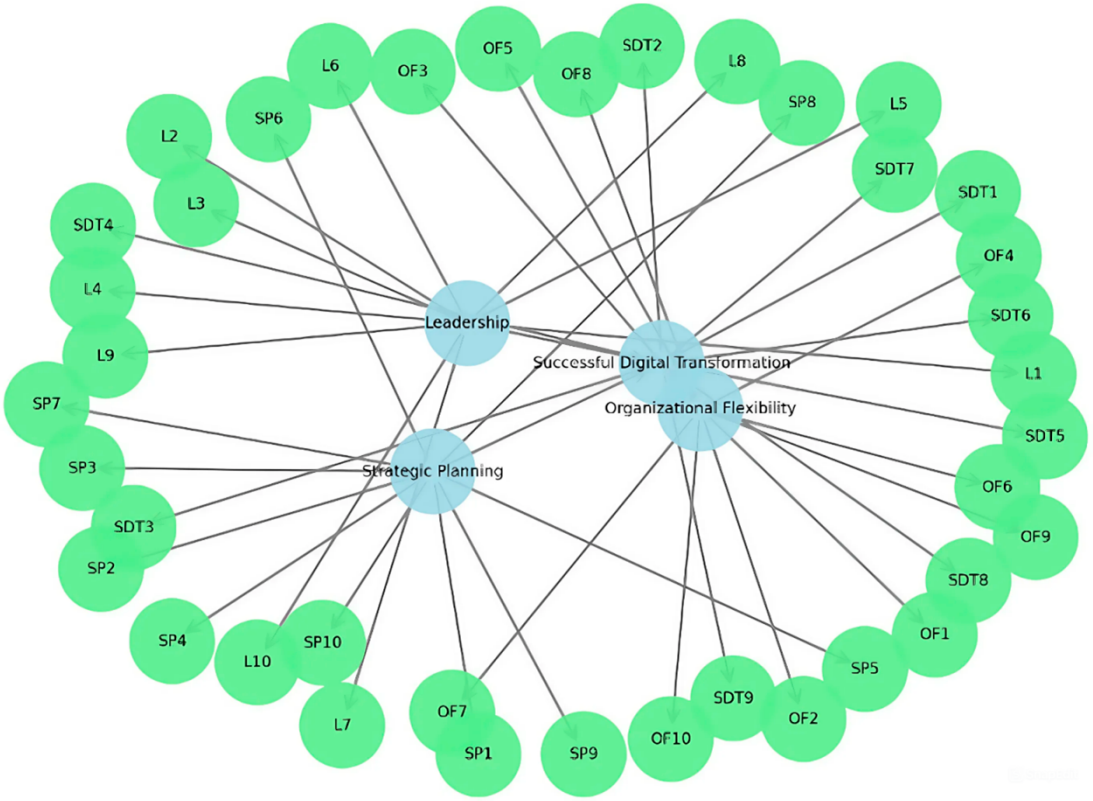


Figure 2. Structural Equation Model (SEM) graph
Source: author's elaboration.

Table 2. Descriptive statistics

Construct	Indicator	Mean	Standard Deviation
Leadership (L)	L1	4.20	0.72
	L2	4.15	0.70
	L3	4.10	0.75
	L4	4.05	0.80
	L5	4.00	0.77
	L6	4.25	0.72
	L7	4.18	0.71
	L8	4.22	0.75
	L9	4.16	0.74
	L10	4.21	0.78

Construct	Indicator	Mean	Standard Deviation
Organizational Flexibility (OF)	OF1	4.25	0.68
	OF2	4.22	0.65
	OF3	4.18	0.70
	OF4	4.12	0.74
	OF5	4.10	0.69
	OF6	4.28	0.72
	OF7	4.20	0.66
	OF8	4.27	0.71
	OF9	4.19	0.69
	OF10	4.24	0.70
Strategic Planning (SP)	SP1	4.30	0.60
	SP2	4.28	0.62
	SP3	4.24	0.64
	SP4	4.22	0.66
	SP5	4.18	0.65
	SP6	4.32	0.63
	SP7	4.29	0.61
	SP8	4.35	0.64
	SP9	4.31	0.66
	SP10	4.30	0.62
Strategic Digital Transformation (SDT)	SDT1	4.35	0.55
	SDT2	4.32	0.57
	SDT3	4.30	0.60
	SDT4	4.28	0.62
	SDT5	4.25	0.58
	SDT6	4.34	0.56
	SDT7	4.29	0.57
	SDT8	4.33	0.59
	SDT9	4.31	0.60
	SDT10	4.36	0.57

Source: author's elaboration.

The measurement model was assessed for reliability and validity. An overwhelming majority of respondents, 82%, agreed that visionary leadership is essential for digital transformation (rating ≥ 4 on a 5-point Likert scale). Leaders who clearly articulate objectives (78%) and inspire and engage their people (81%) were deemed crucial. A significant majority, 75%, reported that their firms possess the capability to promptly adapt to changes (≥ 4). Additionally, 73% acknowledged

the existence of flexible work practices that facilitate innovation, and 80% noted the importance of cross-functional teamwork (≥ 4). Furthermore, 77% confirmed that their firms have a well-defined digital strategy, with 79% noting alignment with overall company objectives and 74% confirming the inclusion of quantifiable goals and key performance indicators (KPIs) (≥ 4).

Table 3a presents the results of the reliability analysis.

Table 3a. Construct reliability

Construct	Cronbach's Alpha	CR	AVE
L	0.89	0.91	0.60
OF	0.87	0.89	0.58
SP	0.90	0.92	0.61
SDT	0.91	0.93	0.63

Source: author's elaboration.

All constructs demonstrated acceptable levels of reliability (Cronbach's alpha > 0.70, CR > 0.70) and convergent validity (AVE > 0.50). The structural model specifies the hypothesized relationships among the latent variables.

To confirm discriminant validity, Table 3b presents the inter-construct correlation matrix with the square root of the AVE on the diagonal, following the Fornell-Larcker criterion.

Table 3b. Inter-construct correlations and discriminant validity

Construct	L	OF	SP	SDT	AVE
L	0.78				0.78
OF	0.45	0.80			0.80
SP	0.50	0.55	0.82		0.82
SDT	0.35	0.45	0.50	0.75	0.75

Source: author's elaboration.

The findings show that the AVE of each construct exceeds its correlations with the other constructs, demonstrating discriminant validity.

The model fit indices are presented in Table 4.

Table 4. Model fit indices

Fit index	Recommended value	Model Value
Chi-square (χ^2)	Non-significant	250.34 ($p < 0.001$)
Root Mean Square Error of Approximation (RMSEA)	< 0.06	0.045
Comparative Fit Index (CFI)	> 0.95	0.96
Tucker–Lewis Index (TLI)	> 0.95	0.95

Source: author's elaboration.

The model fit indices indicate a good fit between the hypothesized model and the observed data (CFI = 0.96, TLI = 0.95, RMSEA = 0.045). Although the χ^2 statistic is significant ($p < 0.001$), this is expected due to its sensitivity to large sample sizes (N = 600); the excellent CFI, TLI, and RMSEA values provide robust evidence of model fit. The standardized path coefficients (β) for the multivariate structural equation model, which represents the simultaneous influence of L, OF, and SP on SDT, are presented in Table 5.

Table 5. Path coefficients

Path	Standardized Coefficient (β)	Standard Error (SE)	p-value
L → SDT	0.35	0.07	< 0.001
OF → SDT	0.45	0.08	< 0.001
SP → SDT	0.50	0.06	< 0.001

Source: author's elaboration.

The path coefficients are all statistically significant ($p = 0.001$), meaning that L, OF and SP have a positive effect on SDT. The findings suggest that all three factors make a substantial contribution to the achievement of digital transformation.

Successful digital transformation relies heavily on effective leadership that encompasses innovative thinking, technical expertise, and the capacity to inspire and encourage personnel. This discovery is consistent with other studies that emphasize the significance of leadership in the process of organizational transformation.

Rapid adaptability to external changes, fostering creativity via flexible work practices, and empowering workers to make choices are essential for achieving effective digital transformation in a business. This outcome emphasizes the need for a flexible corporate culture that welcomes and adapts to change.

A key indicator of successful digital transformation is a well-defined digital strategy that aligns with overall company objectives, includes measurable targets, and involves key stakeholders. This underlines the importance of comprehensive strategic planning focused on digital operations and ensuring alignment with broader corporate objectives.

The findings will be of great importance to companies navigating the complexities of digital transformation. By strengthening leadership qualities, improving organizational flexibility, and developing comprehensive strategic plans, organizations greatly increase their chances of succeeding in digital transformation.

Discussion

The current study's results about the importance of leadership, organizational adaptability, and strategic planning in digital transformation are consistent with and build upon previous research. Prior research also emphasized the significance of leadership in facilitating digital transformation. For example, Chanias, Myers, and Hess (2019) and Guinan, Parise, and Langowitz (2019) found that

visionary leadership and a well-defined digital vision are essential for achieving success in digital efforts. Our findings are consistent with those results, as shown by the substantial path coefficient ($\beta = 0.35$, $p < 0.001$). Meanwhile, Volberda (1996) supports the significance of organizational adaptability, noting that dynamic organizational cultures are more capable of effectively managing swift technology advancements. Our research provides strong evidence that organizational flexibility has a significant impact, as shown by the high path coefficient ($\beta = 0.45$, $p < 0.001$). The significant influence of strategic planning ($\beta = 0.50$, $p < 0.001$) is consistent with the existing strategic management literature (e.g., Ansoff 1987; Grant 2018), which emphasizes the need to integrate digital strategies with broader corporate objectives. Thus, our results demonstrate that leadership, organizational flexibility, strategic planning, and other managerial issues are crucial to the success of digital transformation in the UAE, which supplements technological innovations (such as AI and data analytics.

Our results not only verify the existing evidence from the West, but we goes further by showing that leadership and organizational flexibility are even more significant in emerging markets like the UAE, whereby institutional structures and digital politics are transforming more quickly. This contextual implication offers novel insights into the interaction of organizational enablers and national digital strategies.

Our findings have several practical implications for firms undergoing a digital transformation. They should prioritize the development of leadership competencies that include both visionary thinking and technical expertise, given the crucial role that leadership plays. Leadership development programs should strive to improve leaders' capacity to inspire and encourage personnel while effectively adjusting to swift technological advancements (Westerman, Bonnet, and McAfee 2014).

Furthermore, it is crucial to cultivate a culture that prioritizes adaptability and openness to change. Organizations must endorse adaptable work methodologies, foster interdepartmental cooperation, and provide resources to technology that facilitates remote work and ongoing process improvement. This will enable staff to innovate and promptly adapt to market developments (Volberda 1996). Furthermore, strategic planning is seen as the main element for achieving an effective digital transformation. Organizations must formulate all-encompassing digital strategies that align with their overarching business objectives, establish quantifiable targets, and engage important stakeholders. Consistently evaluating and revising these methods and ensuring sufficient allocation of resources are crucial for sustaining progress in digital projects (Grant 2018).

These practical steps can help companies navigate the complexities of the digital transformation and achieve their strategic goals successfully by prioritizing these practical actions. The findings are particularly valuable to catching-up economies, like those in Central and Eastern Europe (CEE). The visionary thinking and employee engagement in leadership that was evident in the UAE can help CEE firms explore technology adoption in the face of resource limitations. Organizational adaptability in terms of work flexibility and cross-functional cooperation allows these economies to adapt to international digital trends very fast. Therefore, CEE countries can achieve competitiveness in the digital world through strategic planning, which is aligned to national policies such as the UAE AI Strategy 2031. This strategy offers them a roadmap to implement digital strategies that would complement their overall economic goals.

Conclusions

This paper highlights the importance of leadership, organizational flexibility, and strategic planning in the success of digital transformation (SDT) in the UAE. The results show that strategic planning is the most powerful predictor of SDT success ($\beta = 0.50$, $p < 0.001$), followed by organizational flexibility ($\beta = 0.45$, $p < 0.001$), and leadership ($\beta = 0.35$, $p < 0.001$). These findings highlight the significance of management-related aspects in complementing technological changes, including AI and data analytics, which provide the background of digital transformation in the UAE. The research provides empirical suggestions for organizations in emerging economies, including the UAE, to improve their leadership capabilities and create flexibility and strategic plans to make digital transformations successful.

The research used a quantitative technique, which included surveys and questionnaires to mid-to-senior-level managers who were actively involved in digital transformation activities. An online survey was used to gather data from 1000 professionals, resulting in a response rate of 60% (600 valid responses). The data were analyzed using AMOS software and Structural Equation Modeling (SEM), with a specific emphasis on three primary characteristics: Leadership, Organizational Flexibility, and Strategic Planning. The objective was to examine the influence of these components on the success of Digital Transformation.

The results indicate that AI and data analytics provide significant advantages in terms of improving operational efficiency and decision-making. However, it is important to note that human involvement is still crucial and cannot be replaced. Successful digital transformation projects need effective leadership, organizational agility, and strategic planning as important components.

Future research should further explore the particular uses of AI and data analytics in other sectors, analyzing how these technologies might be customized to tackle industry-specific difficulties. Furthermore, conducting longitudinal studies to monitor the progress of digital transformation projects over an extended period will provide useful insights into their long-term effects. By examining the point where AI progress intersects with emerging technologies like blockchain and the Internet of Things (IoT), we may discover new prospects for innovation and improved efficiency. Conducting more research on the creation of educational and training programs that foster the critical human skills needed for digital transformation is crucial for sustaining progress and retaining a competitive edge in the digital era.

Despite the valuable contributions this paper makes, several limitations must be acknowledged. First, the sample was quite small and restricted to mid-level and senior managers, which narrows the aspects of generalizing the findings. Incorporating a more diverse group of participants, including individuals from various organizational levels and geographical areas, would provide a more thorough understanding of the dynamics of digital transformation (Bharadwaj et al. 2013).

Second, the use of self-reported data creates the risk of response bias. Incorporating objective measurements, such as financial performance indicators and customer satisfaction metrics, in future research would be beneficial to supplement self-reported data (Kotter 1996).

Third, the research concentrated more on leadership, flexibility of the organization, and strategic planning without considering other key enablers like organizational culture, skills of employees and technology infrastructure. Thus, further research should investigate these supplementary aspects to provide a more comprehensive perspective on the factors that determine the effectiveness of digital transformation (Teece 2010).

Also, the tendency of means of the items to cluster at 4.0–4.35 with small standard deviations across constructs can restrict the scale discrimination and possibly overestimate interconstruct correlations. Future studies ought to deal with these limitations by including more varied samples, objective performance, more variables and measurement scales that will help increase variability of responses. All three hypotheses developed in the study were empirically verified, confirming the positive and significant impact of leadership, organizational flexibility, and strategic planning on digital transformation success.

References

Ahn, S., Kim, K.S., Lee, K.H. (2022), *Technological Capabilities, Entrepreneurship and Innovation of Technology-Based Start-Ups: The Resource-Based View*, "Journal of Open Innovation: Technology, Market, and Complexity", 8 (3), 156, https://doi.org/10.3390/joitmc8030156

Al Jabri, M.A., Shaloh, S., Nour, S., Haddoud, M.Y., Obeidat, B.Y. (2024), *The impact of dynamic capabilities on enterprise agility: The intervening roles of digital transformation and IT alignment*, "Journal of Open Innovation: Technology, Market, and Complexity", 10 (2), 100266, https://doi.org/10.1016/j.joitmc.2024.100266

Almazrouei, F., Sarker, A.E., Zervopoulos, P., Salman, Y. (2024), *Organizational structure, agility, and public value-driven innovation performance in the UAE public services*, "Heliyon", 10 (13), e33261, https://doi.org/10.1016/j.heliyon.2024.e33261

Ansoff, H.I. (1987), *The emerging paradigm of strategic behavior*, "Strategic Management Journal", 8 (6), pp. 501–515, https://doi.org/10.1002/smj.4250080602

Basole, R.C., Park, H., Seuss, C.D. (2024), *Complex business ecosystem intelligence using AI-powered visual analytics*, "Decision Support Systems", 178, 114133, https://doi.org/10.1016/j.dss.2023.114133

Bertsimas, D., Kallus, N. (2020), *From Predictive to Prescriptive Analytics*, "Management Science", 66 (3), pp. 1025–1044, https://doi.org/10.1287/mnsc.2018.3253

Beushe, W., Szabolch, P., Viktor, M., Jebena, T. (2024), *Responsible Leadership and Organizational Citizenship Behavior: The Mediation Role of Employees CSR Perception*, "Journal of Economic Sciences: Theory and Practice", 81 (2), pp. 117–142, https://doi.org/10.30546/jestp.2024.81.02.06

Bharadwaj, A., El Sawy, O.A., Pavlou, P.A., Venkatraman, N. (2013), *Digital Business Strategy: Toward a Next Generation of Insights*, "MIS Quarterly", 37 (2), pp. 471–482, https://doi.org/10.25300/MISQ/2013/37: 2.3

Chanias, S., Myers, M.D., Hess, T. (2019), *Digital transformation strategy making in pre-digital organizations: The case of a financial services provider*, "The Journal of Strategic Information Systems", 28 (1), pp. 17–33, https://doi.org/10.1016/j.jsis.2018.11.003

Cousins, K., Hertelendy, A.J., Chen, M., Durneva, P., Wang, S. (2023), *Building resilient hospital information technology services through organizational learning: Lessons in CIO leadership during*

an international systemic crisis in the United States and Abu Dhabi, United Arab Emirates, "International Journal of Medical Informatics", 176, 105113, https://doi.org/10.1016/j.ijmedinf.2023.105113

Davenport, T.H., Ronanki, R. (2018), *Artificial intelligence for the real world*, "Harvard Business Review", 96 (1), pp. 108–116.

Fadani, K. (2023), *Impact of Digital Consumption and Factors Affecting It: The Example Of Azerbaijan*, "Journal of Economic Sciences: Theory and Practice", 80 (1), pp. 67–82.

Grant, R.M. (2018), *Contemporary strategic analysis*, Wiley & Sons, Hoboken.

Guinan, P.J., Parise, S., Langowitz, N. (2019), *Creating an innovative digital project team: Levers to enable digital transformation*, "Business Horizons", 62 (6), pp. 717–727, https://doi.org/10.1016/j.bushor.2019.07.005

Jiang, H., Cheng, Y., Yang, J., Gao, S. (2022), *AI-powered chatbot communication with customers: Dialog interactions, satisfaction, engagement, and customer behavior*, "Computers in Human Behavior", 134, 107329, https://doi.org/10.1016/j.chb.2022.107329

Kanungo, R.P., Liu, R., Gupta, S. (2024), *Cognitive analytics enabled responsible artificial intelligence for business model innovation: A multilayer perceptron neural networks estimation*, "Journal of Business Research", 182, 114788, https://doi.org/10.1016/j.jbusres.2024.114788

Kotter, J.P. (1996), *Leading change*, Harvard Business School Press, Boston.

Lada, S., Chekima, B., Karim, M.R.A., Fabeil, N.F., Ayub, M.S., Amirul, S.M., Ansar, R., Bouteraa, M., Fook, L.M., Zaki, H.O. (2023), *Determining factors related to artificial intelligence (AI) adoption among Malaysia's small and medium-sized businesses*, "Journal of Open Innovation: Technology, Market, and Complexity", 9 (4), 100144, https://doi.org/10.1016/j.joitmc.2023.100144

Madanchian, M., Taherdoost, H., Vincenti, M., Mohamed, N. (2024), *Transforming Leadership Practices through Artificial Intelligence*, "Procedia Computer Science", 235, pp. 2101–2111, https://doi.org/10.1016/j.procs.2024.04.199

al-Mutawa, R. (2020), *"I Want to be a Leader, But Men Are Better Than Women in Leadership Positions": State feminism and legitimizing myths in the United Arab Emirates*, "Hawwa", 18 (1), pp. 31–50, https://doi.org/10.1163/15692086–12341369

Nadeem, K., Wong, S.I., Za, S., Venditi, M. (2024), *Digital transformation and industry 4.0 employees: Empirical evidence from top digital nations*, "Technology in Society", 76, 102434, https://doi.org/10.1016/j.techsoc.2023.102434

Ozdemir, S., Arroyabe, J.C.F. de, Sena, V., Gupta, S. (2023), *Stakeholder diversity and collaborative innovation: Integrating the resource-based view with stakeholder theory*, "Journal of Business Research", 164, 113955, https://doi.org/10.1016/j.jbusres.2023.113955

Shao, Z., Zhao, R., Yuan, S., Ding, M., Wang, Y. (2022), *Tracing the evolution of AI in the past decade and forecasting the emerging trends*, "Expert Systems with Applications", 209, 118221, https://doi.org/10.1016/j.eswa.2022.118221

Tagscherer, F., Carbon, C.C. (2023), *Leadership for successful digitalization: A literature review on companies' internal and external aspects of digitalization*, "Sustainable Technology and Entrepreneurship", 2 (2), 100039, https://doi.org/10.1016/j.stae.2023.100039

Teece, D.J. (2010), *Business Models, Business Strategy and Innovation*, "Long Range Planning", 43 (2–3), pp. 172–194, https://doi.org/10.1016/j.lrp.2009.07.003

Tursunbayeva, A., Gal, H.C.-B. (2024), *Adoption of artificial intelligence: A TOP framework-based checklist for digital leaders*, "Business Horizons", 67 (4), pp. 357–368, https://doi.org/10.1016/j.bushor.2024.04.006

Volberda, H.W. (1996), *Toward the Flexible Form: How to Remain Vital in Hypercompetitive Environments*, "Organization Science", 7 (4), pp. 359–374, https://doi.org/10.1287/orsc.7.4.359

Westerman, G., Bonnet, D., McAfee, A. (2014), *Leading digital: Turning technology into business transformation,* Harvard Business Review Press, Brighton.

Westerman, G., Tannou, M., Bonnet, D., Ferraris, P., McAfee, A. (2012), *The digital advantage: How digital leaders outperform their peers in every industry*, "MITSloan Management and Capgemini Consulting", 2, pp. 2–23.

Sukces transformacji cyfrowej w Zjednoczonych Emiratach Arabskich: analiza wpływu przywództwa, elastyczności organizacyjnej i planowania strategicznego z wykorzystaniem modelowania równań strukturalnych

W artykule poddano analizie związki między przywództwem, elastycznością organizacyjną i planowaniem strategicznym oraz wpływ tych elementów na promowanie skutecznej transformacji cyfrowej w Zjednoczonych Emiratach Arabskich. Badanie ilościowe objęło ankiety i kwestionariusze, które zostały rozdane 1000 menedżerom średniego i wyższego szczebla. Dane pochodzące z 600 ważnych odpowiedzi (wskaźnik odpowiedzi równy 60%) zostały przeanalizowane za pomocą modelowania równań strukturalnych (SEM) przy użyciu oprogramowania AMOS. Analiza dotyczyła trzech podstawowych pojęć: przywództwa, elastyczności organizacyjnej i planowania strategicznego oraz ich wpływu na dokonanie udanej transformacji cyfrowej. Wyniki badania pokazują, że 82% uczestników stwierdziło, iż wizjonerskie przywództwo ma zasadnicze znaczenie dla transformacji cyfrowej, 78% podkreśliło potrzebę skutecznego komunikowania celów, a 81% zwróciło uwagę na motywowanie pracowników. Ponadto 75% uczestników stwierdziło, że ich przedsiębiorstwa mają zdolność dostosowywania się do zmian, 73% potwierdziło istnienie elastycznych form organizacji pracy, a 80% podkreśliło potrzebę współpracy międzyfunkcyjnej. Spośród 77% respondentów, którzy stwierdzili, że ich firmy mają jasno określoną strategię cyfrową, 79% dostosowało ją do celów firmy, a 74% uwzględniło wymierne cele i kluczowe wskaźniki efektywności (KPI). Wyniki te podkreślają znaczenie integracji sztucznej inteligencji i analizy danych ze skutecznym przywództwem ludzkim i planowaniem strategicznym. Sugeruje się, aby organizacje wzmacniały swoje zdolności przywódcze, promowały elastyczną kulturę i opracowywały kompleksowe strategie cyfrowe, aby w pełni wykorzystać korzyści płynące z transformacji cyfrowej.

Słowa kluczowe: sztuczna inteligencja, transformacja cyfrowa, przywództwo, planowanie strategiczne, modelowanie równań strukturalnych

Comparative Economic Research. Central and Eastern Europe
Volume 29 Number 1, 2026
https://doi.org/10.18778/1508-2008.29.04

Cryptoassets as a Threat to State Sovereignty in the Field of Enforcement and Insolvency

Martin Cahlík https://orcid.org/0009-0001-4025-8941
Mgr., Faculty of Law, Palacký University Olomouc, Olomouc, Czech Republic, e-mail: martin.cahlik01@upol.cz

Simona Kurtinová https://orcid.org/0009-0003-4273-4635
Ing., Faculty of Law, Palacký University Olomouc, Olomouc, Czech Republic, e-mail: simona.kurtinova01@upol.cz

Michal Kozieł https://orcid.org/0000-0001-8561-0358
Ph.D., Faculty of Law, Palacký University Olomouc, Olomouc, Czech Republic, e-mail: michal.koziel@upol.cz

Michael Kohajda https://orcid.org/0000-0001-7235-0921
doc. JUDr., Ph.D., Faculty of Law, Palacký University Olomouc, Olomouc, Czech Republic,
e-mail: michael.kohajda@upol.cz

Abstract

Cryptoassets, as a novel manifestation of financial technology, pose a challenge to traditional legal frameworks, especially in their decentralised nature and the unique way they are held and transferred. Their emergence requires a re-examination of regulatory principles and mechanisms of rights protection in an environment where decentralisation signifies the absence of centralised control. This article examines cryptoassets as a potential threat to state sovereignty within the domains of foreclosure, enforcement, and insolvency. It analyses the legislative challenges arising from the increasing prevalence of cryptoassets and evaluates the applicability of traditional enforcement law instruments to these new technological contexts. This article also integrates empirical findings from the Czech legal environment into the broader theoretical discourse on financial crime and the erosion of state authority caused by decentralised financial systems operating across national jurisdictions Particular attention is devoted to the technical characteristics of cryptoassets, their legal classification, and the practical obstacles encountered in enforcement and insolvency proceedings, especially in situations where debtors refuse or are unable to provide access to their digital assets.
The analysis also incorporates available statistics on enforcement proceedings and evaluates the Czech legal framework governing cryptoassets, focusing on its implications for the effectiveness of enforcement and insolvency processes.

Funding information: M.C. – Faculty of Law, Palacký University Olomouc, Olomouc, Czech Republic; S.K. – Faculty of Law, Palacký University Olomouc, Olomouc, Czech Republic; M.K. – Faculty of Law, Palacký University Olomouc, Olomouc, Czech Republic; M.K. – Faculty of Law, Palacký University Olomouc, Olomouc, Czech Republic.
The percentage share of the Authors in the preparation of the work is: M.C. – 25.00%, S.K. – 25.00%, M.K. – 25.00%, M.K. – 25.00%.
Declaration regarding the use of GAI tools: Not used.
Conflicts of interests: None.
Ethical considerations: The Authors assure of no violations of publication ethics and take full responsibility for the content of the publication.
Received: 5.08.2025. Verified: 20.10.2025. Accepted: 29.01.2026

The research employs both primary and secondary methods, including legal and technical analysis, modelling of real scenarios, and an examination of the relevant legislative instruments.

Keywords: Czech Republic, cryptocurrency, enforcement proceedings, insolvency, legal framework

JEL: K15, K35, K42

Introduction

In recent years, the dynamics of financial markets have changed dramatically with the emergence of new technologies, particularly cryptoassets based on the principle of distributed ledger technology. While traditional enforcement mechanisms through which a right granted by a decision of a state authority is enforced even against the will of the debtor are established in the Czech legal system on the basis of clearly defined institutions of enforcement and enforcement proceedings, licenced enforcement agents (LEAs), in practice, typically deal with assets that are relatively straightforward to seize from a legal perspective. When digital assets are involved, however, enforcing decisions encounters several legal and technical barriers. This contemporary phenomenon which is simultaneously a practical problem represents not only a legislative challenge but also a socio-economic one, as holders of cryptoassets can relatively easily shield their assets from the exercise of state power authority through conventional enforcement procedures.

The main objective of this study is, therefore, to conduct a comprehensive analysis of the applicability of enforcement instruments to intangible movable assets in the form of cryptoassets and, based on a questionnaire survey, to identify obstacles that arise when enforcing decisions against this relatively new category of property. The study employs a combination of qualitative and quantitative research methods. The analysis of legal regulations relevant to enforcement and digital assets plays a central role, both within the framework of national legislation and in the context of European legal standards. In addition, a technical analysis of the operation and security of cryptoassets was conducted to assess their implications for enforcement.

The methodological framework also includes the modelling of practical scenarios that illustrate potential legal and technical complications in the enforcement of cryptoassets. In particular, the paper focuses on the issues of handling hardware and software wallets, as well as the use of PIN codes, seeds, and passphrases. The empirical part of the work is based on a questionnaire survey conducted among LEAs in the Czech Republic, providing direct insights from practice regarding the feasibility of enforcing decisions by targeting cryptoassets. The analysis of the collected data made it possible to identify key problems encountered by LEAs in their professional activities and provided a factual basis for formulating *de lege ferenda* proposals.

Although the empirical analysis focuses on the Czech Republic, the findings have substantial implications for international research. As a European Union (EU) Member State operating under harmonised European regulation (such as the Markets in Crypto-Assets Regulation (MiCA) Regulation and EU anti-money laundering (AML) directives), the Czech experience serves as a critical "stress test" of these supranational frameworks. If enforcement mechanisms fail in a developed jurisdiction with a robust legal tradition purely due to the technical nature

of cryptoassets (e.g., the existence of private wallets or limited international cooperation), it may be concluded that cryptoassets represent a systemic threat to state sovereignty globally. The obstacles identified are not merely local procedural deficiencies but universal challenges that enable financial crime and facilitate the evasion of sanctions irrespective of the jurisdiction.

Cryptoassets as a Threat to State Sovereignty

Cryptoassets, which the European regulator defines as the "digital representation of a value or of a right that is able to be transferred and stored electronically using distributed ledger technology or similar technology" (Regulation (EU) 2023/1114), have recently become the subject of increasing scholarly and public interest. The nature of cryptoassets and the efforts to regulate them have been examined by, for example, Nabilou (2019), Zetzsche, Arner, and Buckley (2020), Ferreira and Sandner (2021), Kohajda and Moravec (2021), and Hrabčák and Štrkolec (2024), Furthermore, numerous studies have addressed regulation within the EU, a particularly active field, notably by Maume (2023), Van Der Linden and Shirazi (2023), and Kozieł (2025), among others.

However, significant challenges arise when addressing the recovery of cryptoassets in the context of enforcing decisions issued by public authorities. Scholarly literature on this topic remains scarce, as it is a relatively new and rapidly evolving area that, given the technological nature and operation of cryptoassets, is difficult for state authorities to effectively comprehend. At the same time, these issues still lie largely beyond the reach of the expert community. We have therefore relied primarily on legislative sources. Since this article focuses on the Czech Republic, particular attention is paid to Czech legal acts and relevant EU legislation.

A growing body of research demonstrates the extensive misuse of cryptoassets for committing financial crimes. Dupuis and Gleason (2020) analyse various methods and mechanisms by which cryptocurrencies can be employed to circumvent regulatory measures and conduct money laundering, identifying specific instruments, 'open doors', used for this purpose. Irwin and Milad (2016) document the early forms of cryptoasset use in the financing of terrorist activities, highlighting the tendency of extremist groups to exploit these technologies as a means of evading conventional financial and supervisory mechanisms. Heyman (2023) identifies key indicators of fraudulent cryptoasset investment schemes and emphasises the need to systematically apply control mechanisms and warning signals (red flag indicators) for the timely detection of high-risk investment structures in the digital financial environment.

Mackenzie (2024) analyses the collapse of major cryptoasset platforms such as FTX and Celsius, where the cult of personality surrounding key executives normalised fraudulent practices. Kabra and Gori (2023) examine the role of organised criminal groups in drug trafficking on crypto-markets, showing that the advantages associated with this mode of trade outweigh potential risks, making it particularly attractive for organised crime. Wronka (2021a) draws attention to the growing risk of circumventing economic sanctions through digital currencies, which poses a threat to international security. In subsequent research, he identifies new challenges for compliance within the decentralised financial ecosystem (Wronka 2021b). Tiwari

et al. (2024) analyse the use of cryptoassets in geopolitical conflicts, demonstrating how both state and non-state actors can employ cryptoassets to evade international sanctions and finance military operations.

These cases show that the issue of law enforcement in the domain of cryptoassets is not merely a technical or legal challenge, but rather represents a serious threat to state sovereignty over financial flow control and the enforcement of law. Building on the analysis of the Binance case – where the exchange was convicted by U.S. authorities of serious financial crimes, including money laundering and terrorism financing – Cardao-Pito (2025) formulates two fundamental hypotheses concerning the relationship between cryptocurrency exchanges and state sovereignty:

H1: Cryptocurrency exchange organisations can represent a threat to national states because their power to issue assets with properties akin to money may result in the unchecked depletion of the means available for states' lawful financial sanctions over these exchanges.

H2: Cryptocurrency exchange organisations can pose a threat to national states because their ability to issue assets with properties akin to money may result in the unchecked acquisition of resources, allowing them to compete with national states.

These hypotheses are particularly relevant to the issue of enforcement proceedings in the Czech Republic. The first hypothesis suggests that the ability to issue cryptoassets enables debtors to create parallel financial systems beyond the reach of traditional enforcement mechanisms. While the state invests significant resources in building and maintaining its enforcement apparatus, debtors can relatively easily transfer their assets into cryptoassets or use cryptoassets as money, thereby effectively neutralising state or international sanctions.

The second hypothesis highlights a deeper problem: cryptoassets not only allow individuals and entities to evade sanctions but also provide the means for building alternative power structures and establishing markets beyond the supervision of state authorities. In extreme cases, entities holding substantial amounts of cryptoassets may finance their own security forces, infrastructure, or even compete with the state for control over certain territories or sectors of the economy.

Within the context of the Czech legal system, these hypotheses acquire a practical dimension. As our model cases illustrate, a debtor possessing cryptoassets can, in effect, decide whether or not to cooperate with the enforcement agent. Although this article primarily focuses on natural persons rather than legal entities, it is also necessary to point out the potential threat posed by legal persons such as cryptocurrency exchanges or other companies that hold cryptoassets. They may exploit the potential of cryptoassets to position themselves in parity with state power. The absence of effective coercive instruments means that the state monopoly on legitimate force, which forms the cornerstone of modern statehood, is significantly weakened in the sphere of cryptoassets.

The general cases concerning natural persons described later in this article are also applicable to legal entities; however, such entities usually possess considerably greater personnel, as well as infrastructural and financial capacity to use cryptoassets in other ways. As Cardao-Pito (2025)

notes, one of these ways is to create assets (cryptoassets or stablecoins) with properties analogous to money, over which the state has no effective means of seizure or freezing.

European Dimension

A key milestone in the EU's Regulation on Markets in Cryptoassets (Regulation (EU) 2023/1114), which entered into force on 29 June 2023 and became fully applicable on 30 December 2024. This pivotal regulation represents the first comprehensive attempt to harmonise cryptoasset regulation at the supranational level. Its primary objective is to ensure legal certainty and promote innovation while protecting consumers and financial stability. It does so by requiring providers of cryptoasset services and other entities operating in this market to obtain authorisation or a licence from the supervisory authority of an EU Member State.

A key consequence is the European regulator's requirement that service cryptoasset providers must have their registered office within a Member State of the European Union. This ensures that they remain under the close supervision of both national regulators and the EU as a whole. However, from the perspective of this article, even more significant legislation is the implementation of the Regulation of the European Parliament and of the Council (EU) 2023/1113, which obliges cryptoasset service providers to collect essential identifying data of the parties involved in each cryptocurrency transaction and to verify the ownership of crypto wallets. Both types of information are crucial for subsequent audits in tax, criminal, or private-law contexts.

The regulation also devotes considerable attention to stablecoins. Although they represent a smaller share of the cryptoasset market, their importance is fundamental, as they serve as a medium of exchange and a store of value within the cryptocurrency ecosystem. Unlike central bank digital currencies, which constitute a direct digital form of a national currency, stablecoins are issued by private entities, and their value is pegged to a fiat currency, most commonly the U.S. dollar. This similarity to traditional money is the reason why the MiCA Regulation (Regulation (EU) 2023/1113) imposes stricter rules on them than on other cryptoassets. The regulation establishes limits on transaction volumes, mandates the redemption of tokens at full nominal value, and prohibits the payment of interest to prevent their speculative use. These measures aim to strengthen the stability of stablecoins, enhance consumer protection, and avert the risk that they could disrupt the EU's monetary policy or financial stability.

Although this represents a major step forward in the regulation of cryptoassets at the EU level, there is still no European legislation requiring providers of cryptoasset-related services to cooperate with the state authorities of a Member State other than the one in which they have their registered office, even if they operate within that country.

A similar problem to the one discussed in this article can also be identified in Poland, a country closely related to the Czech Republic both in terms of social development and legal tradition. Poland is likewise seeking ways to enforce cryptoassets as efficiently as possible. The starting point for Polish legal theory and practice is the definition of a cryptoasset as a property right, established by the jurisprudence of the Polish Supreme Administrative Court (Judgment of the Supreme Administrative Court of 6 March 2018). From this interpretation, it follows that

a cryptoasset may be subject to enforcement under Article 909 et seq. of the Polish Code of Civil Procedure (Act of 17 November 1964 – Code of Civil Procedure).

According to Article 801–1 of the Polish Code of Civil Procedure, the debtor is obliged to submit to the enforcement officer, either orally for the record or in writing, an inventory of assets together with a declaration of its accuracy and completeness, under the threat of criminal prosecution for making a false statement. However, a similar problem arises here as in most EU Member States: if the debtor fails to cooperate with the enforcement officer, the latter has, apart from the threat of criminal prosecution, very limited means to compel the debtor to disclose access codes or surrender a hardware wallet.

If the cryptoassets are held on an exchange, the situation is analogous to that in the Czech Republic, as the procedure follows the unified framework of European legislation. In such cases, the enforcement officer may request the exchange to block the debtor's cryptoassets in their account, and the exchange is obliged to cooperate with and comply with the enforcement officer's request.

We are aware that this journal focuses on comparative studies; however, given that the situation in each Member State is highly specific and that a direct comparison of the issues examined here would far exceed the permissible length of the article, we have chosen to concentrate primarily on enforcement and insolvency proceedings in the Czech Republic. This focus is further justified by the fact that the questionnaire survey was conducted in the Czech Republic among Czech enforcement agents; therefore, the present study primarily addresses the Czech context, which best corresponds to the data obtained.

Our objective is thus mainly to highlight the specific features of the Czech system, which may subsequently serve as a source of inspiration for other jurisdictions when addressing similar issues already resolved in the Czech Republic. More importantly, we hope the example of insufficient Czech solutions will stimulate a Europe-wide expert discussion that will lead to or at least contribute to the establishment of unified rules within the EU.

As regards the actual enforcement of decisions, two basic scenarios can be distinguished in general terms. The first scenario concerns a debtor who holds cryptoassets recorded in some manner on a regulated exchange (for example, through an account with an entity subject to European regulation). In this case, the rules are harmonised within the EU. Centralised cryptoasset exchanges are obliged to maintain relatively detailed records of their clients. Theoretically, this gives the state a more straightforward position, since the enforcement of cryptoassets in this context closely resembles the enforcement of ordinary financial funds held in bank accounts. In practice, however, numerous practical limitations persist, most notably the continuing inadequacy of international cooperation in this field.

For example, Czech enforcement agents reported in the questionnaires that foreign exchanges often fail to respond to their inquiries regarding the existence of a debtor's account. At this point, the most feasible approach involves cooperation through national regulators supervising exchanges in the respective jurisdictions. The remaining rules arising from the MiCA Regulation

or AML measures are uniform across the EU, as they have been adopted in the form of directly applicable regulations.

The second enforcement scenario is considerably more complex (as we illustrate further using the example of the Czech Republic). If the debtor holds their cryptoassets in a private hardware wallet, then without the debtor's cooperation, under current legal instruments, the state's enforcement capabilities are limited or non-existent. At present, all EU Member States face the same or similar challenges and continue to seek appropriate solutions, thus far without success.

Enforcement Proceedings and Other Forms of Enforcement in the Czech Legal System

Enforcement, the final stage of the civil process that involves the compulsory enforcement of a right granted by a court, is based on a duality of legal frameworks in the Czech legal system.

The enforcement of a decision represents the older form of enforcement and is regulated by Section 251 of Act No. 99/1963 Coll., the Code of Civil Procedure. It constitutes judicial enforcement, meaning that enforcement is ordered and executed directly by a judicial authority. This form of enforcement is, however, a somewhat rigid instrument, used in practice only in specific legal cases or situations where no other method of enforcement is available.

By contrast, enforcement proceedings represent a newer form of enforcement, governed by Act No. 120/2001 Coll., the Enforcement Code. In this case, enforcement is carried out by a private business owner – a natural person authorised by the state to operate an enforcement office who is thus empowered both to order and to perform enforcement independently (Act No. 120/2001 Coll., § 1 (1)). This person is designated as an LEA and must be of good moral character and integrity, hold a university degree in law (or an equivalent degree in the field of legal sciences), have at least three years of professional practice in enforcement activities, and successfully pass the enforcement agent's examination (Act No. 120/2001 Coll., § 9 (1)).

Both forms of enforcement require the existence of an enforcement title (Act No. 99/1963 Coll., § 261 (2); Act No. 120/2001 Coll., § 37 (2)), i.e., a decision or another title expressly defined by law (or a similar decision), accompanied by a confirmation of enforceability issued by the competent authority. Enforcement titles are largely identical under both legal regimes, although the enforcement of a decision may also rely on historically obsolete titles (e.g., enforceable decisions of state notaries). The Enforcement Code titles are broadly defined as "an enforceable decision of a court or other authority active in criminal proceedings, if it grants a right or affects property, an enforceable decision of a court or licenced enforcement agents, if it grants a right, obliges to an obligation or affects property, an enforceable arbitration award, a notarial deed with permission for enforcement, an enforceable decision and another enforcement title of a public authority and other enforceable decisions and approved settlements and documents, the enforcement of which is permitted by law" (Act No. 120/2001 Coll., § 40 (1)). The enforcement

of a decision may be initiated based on similar enforcement titles, provided that they are designated as such by law.

However, decisions issued in administrative or tax proceedings are excluded from judicial enforcement. It is therefore impossible to order or execute enforcement based on these titles within that framework (Act No. 99/1963 Coll., § 274 (1)). This limitation, however, does not apply under the Enforcement Code, meaning that such decisions can, in principle, be enforced through enforcement proceedings. Nevertheless, such cases are relatively rare, since administrative and tax enforcement are governed by their own special procedures, which are generally more suitable for enforcing such decisions. It is anticipated that the limitations on enforcing cryptoassets within administrative or tax proceedings will be similar to those encountered in enforcement proceedings or the judicial enforcement of decisions.

In both enforcement proceedings and the enforcement of a decision, enforcement is initiated exclusively at the request of the person entitled under the enforcement title. Thus, there is no automatic stage within the Czech civil process that compels the debtor to comply voluntarily with the decision.

Under the Enforcement Code, the process begins with an enforcement motion that must designate the LEA who will carry out the enforcement. The motion must satisfy the general requirements applicable to submissions: it must specify the petitioner, the subject matter, and the relief sought, and it must be duly signed and dated. It is also necessary to identify the debtor (i.e., the obligor), state the obligation to be enforced, and precisely indicate the enforcement title (Act No. 120/2001 Coll., § 38 (1)). Once the LEA selected by the entitled person who may freely choose from all LEAs in the Czech Republic – receives authorisation from the competent court, the agent performs almost all procedural acts independently, without further cooperation from the entitled party, including determining the method by which the enforcement will be executed.

Under the Code of Civil Procedure, enforcement follows largely the same principles, but with key differences. When enforcing a monetary obligation, the motion must also specify the method of enforcement for example (e.g., wage deductions, garnishment of receivables, or the sale of movable or immovable property) (Act No. 99/1963 Coll., § 258 (1), § 261 (1)) This requirement, which is fundamental for the seizure of cryptoassets, considerably reduces the suitability of judicial enforcement for such cases. When dealing with a monetary claim, the entitled party usually selects a method likely to yield liquid assets. Therefore, without any other information about the debtor, they will most likely propose the sale of movable property as an *ultima ratio* method of enforcement.

It should also be noted that even if the application for enforcement lists all methods of enforcement, it is unlikely to succeed, since both the court and the bailiff must act in accordance with the principle of proportionality, proceeding from less intrusive means (such as wage deductions) to those capable of affecting a broader range of the debtor's property. Moreover, if the debtor does not personally hold the cryptoassets, the application must specify the person or entity that holds them. Unlike LEAs, courts and judicial bailiffs lack specialised instruments

to locate or seize cryptoassets, which makes the choice of judicial enforcement highly inefficient when the debtor is presumed to own such assets.

It should further be emphasised that, in the case of judicial enforcement, the applicant cannot choose any court to order and carry out the enforcement; jurisdiction lies exclusively with the debtor's general court, i.e. the court in whose district the debtor has their place of residence or registered office. Thus, if the entitled party opts for this rigid form of enforcement, disregarding the aforementioned procedural and practical obstacles, they will ultimately face the same limitations as those encountered by LEAs in enforcement proceedings. The individual cases discussed below will therefore illustrate problems that are, at least theoretically, identical across both forms of enforcement.

Current Enforcement Trends in the Czech Republic

Recent enforcement proceedings in the Czech Republic reveal concerning trends that merit attention in the context of the interaction between traditional enforcement mechanisms and emerging technologies such as cryptoassets. According to publicly available statistics for 2024, approximately 3.3 million enforcement proceedings were initiated in the Czech Republic, reflecting the extensive reliance of the enforcement apparatus. This considerable volume of enforcement activity poses not only administrative challenges for the state but also significant socio-economic consequences for the population.

The financial dimension of these enforcement proceedings illustrates their economic significance. Enforcement authorities have recovered roughly CZK 568 billion (approximately EUR 22 billion), demonstrating the magnitude of the financial flows subject to state enforcement powers. Notably, the average amount per enforcement proceeding stands at CZK 922,615 (approximately EUR 36,700) (Institut prevence a řešení předlužení, 2025a). This figure substantially exceeds the country's annual gross average wage (CZK 590,748, or around EUR 23,500) (Český statistický úřad, 2025), indicating a systemic debt trap rather than isolated cases of insolvency.

An age-based analysis further reveals that the enforcement burden is most pronounced in the working-age population, peaking in the 45–49 age group (over 80,000 individuals), and significantly affecting those aged 35–54 (Exekutorská komora České republiky, 2025). Geographically, strong regional disparities persist: while north-western regions record enforcement rates of up to 12.8%, central parts of the country show values below 4%. This uneven distribution suggests that the socio-economic factors driving enforcement are territorially concentrated (Institut prevence a řešení předlužení, 2025b).

Although the trend between 2022 and 2025 shows a modest decline from 7.5 to 6.6% in the overall proportion of individuals under enforcement (Institut prevence a řešení předlužení, 2025c), the share of multiple enforcement proceedings remains persistently high at 76–77% (Institut prevence a řešení předlužení, 2025d). The decrease in the total number of individuals enforcement cases since 2023 is primarily attributable to the entry into force of Amendment No. 286/2021 (Part 2, Amendment Point 94), which introduced the institution of terminating "unsuccessful enforcements". This legislative measure allows for the discontinuation of enforcement proceedings

once two cumulative conditions are met: (1) the absence of any recovery sufficient to cover the enforcement costs during the previous six years, and (2) the absence of any seizure of the immovable property within the given enforcement proceedings.

These data provide essential context for discussing cryptoassets. Individuals facing significant enforcement pressure may be increasingly inclined to seek alternative financial instruments beyond the reach of traditional enforcement mechanisms, thereby creating new regulatory challenges at the intersection of digital technologies and legal enforcement. The statistical analysis of enforcement proceedings in the Czech Republic thus provides a crucial socio-economic background for assessing the enforceability of cryptoassets. Given the sheer number of enforcement cases, as well as their economic magnitude and structural nature, the issue of digital-asset enforceability is becoming increasingly relevant. High levels of indebtedness and the prevalence of multiple enforcement proceedings exert strong pressure on debtors, who may perceive cryptoassets as a means of shielding part of their assets from enforcement sanctions.

Cryptoassets as a Matter of Law

When considering the enforcement of cryptoassets, it is first necessary to determine their legal nature under Czech law. For an object to quality as a "thing" in the legal sense within the meaning of the Czech Civil Code, it must cumulatively meet two legal characteristics: it must be distinct from a person and must serve human needs (Act No. 89/2012 Coll., § 489). The Code also contains a negative definition, expressly providing that a thing is not the human body or its parts, and that living animals are likewise not regarded as things. These entities are therefore explicitly excluded from the concept of a "thing". Cryptoassets do not fall into any of these excluded categories and thus satisfy the first requirement – their distinctness from a person – without difficulty. The analysis must therefore focus on the second requirement, namely whether cryptoassets can "serve human needs" within the meaning of the Civil Code.

Legal theory further supplements this definition by adding an essential attribute namely, that a thing must be capable of being the object of subjective property rights, particularly the right of ownership (Dvořák, Švestka, and Zuklínová 2006:377). This requirement may be derived indirectly from the Civil Code's definition of a tangible thing as a controllable part of the external world that possesses the character of an independent object (Act No. 89/2012 Coll., § 496 (1)). It logically follows that an object which cannot be controlled cannot serve as the object of private property rights and therefore cannot qualify as a thing within the meaning of the Civil Code, even if it exists as a physical entity.

When assessing these conditions, it is evident that cryptoassets are neither natural persons (§ 23) nor legal persons (§ 118) under the Civil Code. Furthermore, they demonstrably serve human needs, and their utility is further corroborated by legal definitions, for instance, in the European Regulation on cryptoassets, which Czech law incorporates by reference. Section 4 (8) of Act No. 253/2008 Coll., on specific measures against the legalisation of proceeds from crime and the financing of terrorism refers to the European Regulation on cryptoassets, which defines them as "a digital representation of value or a right that can be transferred or stored electronically using distributed ledger technology or similar technology" (Regulation (EU) 2023/1114, Article 3 (1)(5)).

Cryptoassets also satisfy the third and final criterion for classification as a legal "thing": they are capable of constituting the object of subjective property rights, as they can be possessed, transferred, or traded. From a legal standpoint, having satisfied all three cumulative requirements (distinct from a person, serving human needs, and being capable of holding private property rights), cryptoassets therefore qualify as "things" under the Civil Code. This conclusion is supported by the interpretation of Section 489, which encompasses a wide range of tangible and intangible objects within its broad definition. The current Civil Code deliberately adopts a more comprehensive conception of "thing" than previous legal regulations, drawing on pre-war Czechoslovak jurisprudence and expressly departing from the narrowly materialistic understanding that is characteristic of the twentieth century. According to Section 489, "things" include both tangible and intangible objects, such as industrial property rights, book-entry securities, and various financial instruments.

Regarding the classification of property as tangible or intangible, unlike fiat currencies, cryptoassets have no physical counterpart. They exist exclusively in a decentralised digital environment without territorial boundaries. Their existence depends on the technological infrastructure of distributed networks, which facilitates nearly instantaneous and cost-effective international transfers of value without the involvement of the traditional banking system. The technological foundation of these innovative financial instruments lies in distributed ledger technology, which fundamentally alters the methods of storing and sharing information. Unlike centralised database systems managed by a single authority, distributed ledger technology enables the distribution and synchronisation of data across multiple computer nodes without reliance on a central repository.

Pursuant to Section 498 (1) of the Civil Code, immovable property comprises land, underground structures with a specific purpose, property rights relating thereto, and rights that are expressly designated by law as immovable property. All other objects, whether tangible or intangible, are deemed movable. In light of these considerations, cryptoassets must be classified as intangible movable property under private law (Act No. 89/2012 Coll., § 496). They may also be regarded as fungible (i.e., that one unit of the cryptoasset is interchangeable with any other unit of the same type).

Based on the foregoing analysis of the legal nature of cryptoassets in relation to the provisions of the Enforcement Code, several fundamental conclusions may be drawn for enforcement proceedings. Since cryptoassets satisfy the requirements for classification as intangible movable property under the Civil Code, they fall within the scope of enforcement under Section 59 (1) (c) of the Enforcement Code, i.e., by way of the sale of movable property. This means that, when enforcing a monetary claim, an LEA may seize a debtor's cryptoassets in the same manner as other movable property in its possession. Nevertheless, the technical specificities of cryptoassets present substantial practical challenges for enforcement proceedings, which will be further illustrated in the following model situations.

Challenges in the enforcement of Cryptoassets

The technological characteristics of cryptoassets pose fundamental challenges for their enforcement proceedings. Unlike traditional financial instruments tied to a specific regulatory and geographical framework, cryptoassets exist in a decentralised digital environment beyond state borders. Their architecture, based on the technological infrastructure of distributed networks, enables almost immediate and cost-effective international value transfers without involving the traditional banking system. Additionally, the person who developed a particular cryptoasset usually has no right, or even the ability, to intervene in this technological system and, therefore, cannot respond to any calls for cooperation or to freeze or seize cryptoassets. This aspect disrupts the established financial flow principles and presents new challenges for enforcement authorities and current legislation. Cryptoassets are usually based on three basic factors:

1. A form of distributed ledger technology (DLT) technology that allows information to be stored via a distributed ledger.
2. Cryptographic information security and identity verification that uses asymmetric cryptography.
3. Decentralisation.

A distributed ledger based on DLT technology allows information to be stored, processed, and recreated anywhere in the world. It uses a decentralised system of users who, if they meet the requirements of the network on which the distributed ledger is maintained, and can process and store information in the distributed ledger for some form of reward. Once the information is stored, other users verify its authenticity based on predetermined criteria and synchronise their distributed ledger with this new information. It is therefore clear that no central entity would authoritatively decide what information will be on the network or how it will be handled. Still, it is necessary for all users processing this information to agree to this.

All information on the network of individual cryptoassets is then encrypted so that the content of the information is known only to the parties concerned, i.e., the person who created the information and the people to whom it was sent. This is done using asymmetric cryptography, a technology where the sender encrypts information using a public key, and the recipient can only decrypt it using their corresponding private key.

Cryptoassets are stored in "crypto wallets", which are categorised as either hot or cold. Hot wallets are constantly connected to the internet and exist only as a specific type of software. Cold Crypto wallets (e.g., Trezor or Ledger) are physical devices whose software connects to the Internet only when a transaction is made (Takei and Shudo 2024:747–765). A crypto wallet has a public identifier, known as a public address, for third parties. A public address can be likened to a bank account number; it is usually a public key that is modified using mathematical operations (hashing). For example, the public address of the first Bitcoin wallet belonging to Satoshi Nakamoto is: 1A1zP1eP5QGefi2DMPTfTL5SLmv7DivfNa.

The security of these crypto wallets is also based on asymmetric cryptography, where the public key verifies you as the owner of the public address to which you can send or receive cryptoassets

(Xu, Weber, and Staples 2019:30–31). The private key serves as a password to access the crypto wallet; without it, neither the wallet nor the cryptoassets stored within can be controlled. Above the private key is a "superior master key" a recovery phrase called a "seed". This phrase comprises twelve or twenty-four words (Kaliský 2018:40), from which the private key is subsequently derived. The seed is created when the wallet is generated, and it must be recorded on a reliable medium or memorised. If the user forgets the private key, the wallet can be restored using the seed by correctly entering the words in the original order. If the seed is forgotten, there is almost zero chance of reassembling it and restoring the crypto wallet.

While crypto wallets incorporate robust security, two additional features are key in enforcement proceedings. The first is the PIN, which can be set for cold wallets. This numeric combination must be entered before the user can operate the wallet. If the user forgets the PIN, they cannot connect to the wallet, but access to the cryptoassets is still possible using the seed. If the PIN is entered incorrectly, the time delay for re-entering the PIN usually doubles, but only up to a point when the wallet's contents are completely erased, forcing recovery solely via the seed.

The most problematic security feature from the point of view of enforcement proceedings is the passphrase technology (loosely translated as "access phrases"), which allows the user to add additional and primarily custom words to the seed. This process creates a secondary cold wallet that can be restored using both the seed and the passphrase. If a user moves all their cryptoassets to this new crypto wallet with a passphrase, no other user can obtain the cryptoassets without knowing the phrase, even if they know the seed. The passphrase is not stored on the crypto wallet itself, but on the chip of this wallet, meaning that even if someone gains unauthorised access to the crypto wallet, they will not find this passphrase.

In the context of recovering cryptoassets, the provisions of Section 58 of the Enforcement Code are both extremely important and highly problematic. The law exhaustively defines the methods of enforcement but does not explicitly mention the seizure of cryptoassets as a distinct method. This raises the first significant legal question: under which existing method can cryptoassets be classified? The most likely classifications are under Section 58 (2)(b) as "severance of other property rights" or under Section 58 (2)(c) as "sale of movables", given their character as intangible movables. However, this classification runs counter to the technological specifics of cryptoassets, particularly their decentralised nature and the method of securing them through asymmetric cryptography.

The legal provision also establishes a sequential order of enforcement methods, with the seizure of other property rights or the sale of movables used only after less invasive methods have been exhausted. This procedure may complicate the timely seizure of cryptoassets, which can be quickly transferred to other addresses or exchanged for other assets. The time delay imposed by the legal order may ultimately prevent the effective seizure of cryptoassets, as the debtor has enough time to move them out of the enforcement agent's reach. A special problem is also posed by the provision of Section 58 (1), which limits the seizure of assets to the extent that it is "safely sufficient" to cover the claim being enforced and the related costs. For cryptoassets, whose value can fluctuate significantly, it is difficult to determine a safe and sufficient extent, which may lead to excessive or insufficient seizure due to market volatility. However, it is very likely that "market volatility" will

be the very reason under which "safely sufficient" seizure will be subordinated. Therefore, it will be irrelevant whether the bailiff seizes more than the claims and the costs of conducting the enforcement. However, after paying the claim and the costs of conducting the enforcement, the LEA will be forced to return the remaining portion of the funds they collect from the sale of cryptoassets to the debtor. In addition, debtors may intentionally disperse their cryptoassets among many wallets with small balances, thereby making comprehensive seizure more difficult and reducing enforcement efficiency due to the costs of securing them.

Due to the nature of cryptoassets, proving debtor ownership may be difficult, especially if the cryptoassets were acquired through foreign cryptocurrency exchanges or decentralized finance (DeFi), which is a relatively common phenomenon. The possibility of establishing the existence of such assets is significantly limited in enforcement proceedings. In addition, cryptoassets are often held in anonymous wallets, in wallets of foreign cryptocurrency exchanges outside the Czech Republic's jurisdiction, or in completely autonomous and independent systems.

In enforcement proceedings, the debtor may be requested to provide information about their assets, including cryptoassets. Cooperation from a third party, such as a domestic cryptocurrency exchange or digital asset provider, may also be requested. However, even if the existence of cryptoassets is established, there is no guarantee that they will be effectively secured, let alone sold in enforcement proceedings. If the assets are stored on foreign platforms, asserting a claim against those entities is impossible from the perspectives of both the Czech legal system and European standards. In that case, it is legally very complex and financially costly. The absence of specific legal standards governing the enforcement of cryptoassets, combined with the higher costs and time-consuming enforcement processes associated with them, makes the entire procedure considerably inefficient and, in many cases, practically unfeasible.

One of the key aspects of successful asset recovery is not only their acquisition but also their subsequent safekeeping (Act No. 120/2001 Coll., § 46 (5)). For example, Erp (2022:22–25) emphasises that, after obtaining control over cryptoassets (either by obtaining a private key or by direct transfer), the LEA must securely deposit these assets in a separate wallet that functions as a trust account. This specific wallet must ensure the separation of the secured cryptoassets from other assets and protect them against possible further enforcement, a crucial technical and procedural aspect of managing cryptoassets in the enforcement proceedings. If it is impossible to store cryptoassets in a hardware wallet, the LEA is forced to secure a specialised custodian to ensure the custody of these cryptoassets for the LEA; however, this procedure will increase the cost of securing assets during enforcement.

In this context, LEAs must acquire and further develop a deep and comprehensive knowledge of the technologies behind cryptoassets, which is key to effective enforcement. From a procedural perspective, LEAs must also develop and implement standardised procedures for handling digital assets that reflect their specific nature, which is different from traditional forms of property. This includes, among other things, a documented process for receiving, storing, and subsequently transferring cryptoassets, including consistent logging of all operations to ensure transparency of the entire process. It is also necessary to ensure the careful and comprehensive handling of these cryptoassets within the framework of internal and external processes

related to the transfer of cryptoassets between individual crypto-wallets, since a single error when transferring cryptoassets can mean absolute loss, leading to the financial liability of the LEA for this damage caused.

If the LEA manages to recover the relevant units of cryptoassets, another potentially problematic process comes into play: their subsequent monetisation. The current practice of other state authorities[1] is to sell the received cryptoassets in the form of an auction, which is preceded by the publication of the auction decree. Although this method achieves the desired result, it also introduces many uncertainties that can be fundamental to the process.

The first issue is determining the lowest bid. Current practice tends to leave the lowest bid undefined, linking it to the asset's value at a specific time at an electronic address on the Internet. Specifically, it is possible to identify the determination of the lowest bid as "the amount of the XBP index at 8:00 a.m. CET on the day the auction begins within the meaning of Article 8, paragraph 9 of the Auction Rules" (Daňhel 2025: 3). The price at this specific moment may already be significantly below (or above) the price stated in the item list. Conversely, after the auction, the bidder remains in a state of uncertainty for a relatively significant period as to when the movable property will arrive in their electronic wallet. Given the relatively high volatility in cryptoasset markets, this time lag can be a significant problem for the bidder. It is also highly likely that the bidder will not receive the full amount of the cryptoasset offered, as it will always be reduced by the blockchain transaction fee, which can be highly variable depending on the type of cryptoasset. However, since private sales are not permitted in this case, an auction is the only possible method.

As demonstrated by the growing body of research on financial crime associated with cryptoassets, law enforcement in this area is not merely a matter of legislative gaps but represents a complex institutional and technological challenge. The successful enforcement of cryptoassets requires far more than an adequate legal framework; it demands specialised human resources, advanced technologies, and international coordination.

For instance, European Commissioner Mairead McGuinness has repeatedly emphasised the need for cross-border collaboration and the harmonisation of regulatory approaches (Jones 2023). The Bank for International Settlements similarly notes that the global nature of cryptoassets poses challenges that necessitate coordinated regulatory action. Where regulatory gaps and inconsistencies exist between jurisdictions, the associated risks cannot be fully mitigated (Ocampo, Branzoli, and Cusmano 2023).

Morton (2020) advocates for the establishment of a unified system of regulatory rules and competent supervisory authorities, recommending that such institutions be vested with the power to impose sanctions and criminal penalties to strengthen cybersecurity and combat illicit activities involving cryptoassets. As Cardao-Pito (2025) points out, the successful enforcement of cryptoassets in criminal proceedings requires specialised police units that are sufficiently trained and equipped with the technological tools and resources necessary to combat financial crime. Enforcement agents in the Czech Republic currently lack these capacities to a sufficient extent.

1 In this case, the Ministry of Justice of the Czech Republic.

Effective enforcement of cryptoassets, therefore, requires not only legislative reforms but also investments in technological infrastructure enabling the tracking of blockchain transactions, enhanced international cooperation (since cryptoassets by their very nature transcend national jurisdictions), and continuous professional training of LEAs in this rapidly evolving field. Without these institutional and technological capacities, even the most sophisticated legislative provisions will remain a *lex imperfecta* a dead letter of the law.

Model Cases That May Arise When Executing Cryptoasset Decisions

The following scenarios outline several model situations that may arise during enforcement proceedings in which cryptoassets will be affected. For these models, we assume that the LEA makes all possible legal efforts to satisfy the creditor's claim and the debtor has no other assets; therefore, any primary enforcement order has been unsuccessful.

Model situation No. 1

Filip is a long-time investor in speculative cryptoassets, which he regularly buys for cash at a Bitcoin ATM and transfers to the public address of his digital crypto wallet. He has no information stored and remembers his seed. Filip is subject to enforcement proceedings and, when requested to declare his assets, denies ownership of the cryptoassets.

This situation is relatively straightforward. Since the debtor did not declare ownership of the cryptoassets in the asset declaration and the cryptoassets are stored in a digital crypto-wallet, the LEA has no way of knowing about their existence and, consequently, cannot order or carry out the enforcement. If Filip purchased the cryptoassets through his bank account, it is possible that the bailiff could identify the cryptoassets using a bank statement. Still, recovery would likely still be impossible.

Model situation No. 2

Filip is a long-time investor in speculative cryptoassets, which he regularly buys in cash at a Bitcoin ATM and transfers them to the public address of his hardware crypto wallet, which is physically located at his residence. He does not have any information stored about this wallet; he remembers his seed and has set a PIN on the crypto wallet. Filip is subject to enforcement and, when requested to declare his assets, denies ownership of the cryptoassets.

Within model situation No. 2, it is possible to consider the following options:

- *Variation 2.1: Filip has his seed written on a piece of paper, which he does not keep with his wallet. A PIN does not protect the crypto wallet.*
- *Variation 2.2: Filip has his seed written on a piece of paper that he does not keep with his wallet. The crypto wallet is protected by a PIN that Filip has not stated anywhere.*
- *Variation 2.3: Filip has his seed written on a piece of paper (but also memorised), which he keeps next to his crypto wallet. He also has his PIN written next to the seed.*

- *Variation 2.4: Filip has his seed written on a piece of paper that he keeps near his crypto wallet. He also has his PIN written next to the seed, but Filip has a set passphrase in his head, which secures all cryptoassets in a hidden wallet.*
- *Variation 2.5: Filip's hardware wallet is not located at Filip's residence.*

This situation differs from Model Situation No. 1. In the event of a movable enforcement, the LEA may find the hardware wallet, label it with a sticker, and ensure its transport to the enforcement warehouse. However, this transfer only occurs after the specified period has elapsed, allowing the debtor an opportunity to dispose of the cryptoassets, although he should not do this.

A complex situation then arises: the LEA possesses the crypto wallet (which holds access to the cryptoassets), but lacks the ability to dispose of the cryptoassets. After all, he does not know the PIN or the seed required for restoration. At this stage, the LEA has three basic options: a) invite the debtor to provide the PIN, b) invite the debtor to provide the seed, and c) set the crypto wallet to factory settings.

If the debtor refuses to provide the PIN or seed, the LEA can impose administrative fines until the information is provided. However, the debtor can simply tell the LEA that he does not remember either key. In that event, the LEA has no choice but to reset the crypto wallet and sell it for its usual value.

Variation 2.1 offers the potential for the first successful enforcement. Upon seizing the wallet and finding the seed, the LEA can transfer the cryptoassets to their own hardware (or other) crypto wallet and proceed to auction them.

Variation 2.2 offers the potential for a second successful enforcement. Once the LEA has performed all the actions within the movable enforcement, they can bypass the PIN on the hardware wallet by restoring the wallet (or cryptoassets) to another wallet using the seed, and then auction the assets.

Variation 2.3 follows the same procedure as the previous two variations, offering another successful enforcement possibility.

However, it is important to note that in scenarios 2.1–2.3, an alert and quick debtor can still outrun the LEA and restore the cryptoassets by using the seed, even without the physical crypto wallet. If the agent discovers the seed was used and the cryptoassets are elsewhere, they revert to the difficulties of the general model situation No. 2. While criminal sanctions are theoretically possible for the debtor, the creditor may gain nothing from either the enforcement or criminal proceedings.

Variation 2.4 is similar to Variation 2.3, but includes the complicating factor of the passphrase. Even though the LEA seizes all essential components (crypto wallet, PIN, and seed), they only gain access to the empty "basic" wallet. The assets remain secured in the hidden wallet, which is accessible only after entering the passphrase. The LEA cannot recover the assets by restoring the cryptoassets to another wallet since they still do not know the passphrase, a mandatory prerequisite for successfully restoring cryptoassets to a newly created (or existing) crypto wallet.

The agent is again forced to rely on the debtor's cooperation or merely monetise the hardware wallet device.

Variation 2.5 is almost certainly destined to fail. Since the LEA does not have any information about the debtor's ownership of cryptoassets, there is no possibility of seizing the debtor's cryptoassets or imposing recourse for the debtor's non-cooperation during the enforcement.

Model situation No. 3

Filip is a long-time investor in speculative cryptoassets. He regularly buys these cryptoassets on a cryptocurrency exchange and leaves them in the exchange's electronic wallet. Filip is subject to enforcement and, when requested to declare his assets, denies ownership of the cryptoassets.

This option represents "the light at the end of the tunnel" for the LEA, as there is a relatively easy and realistic way to access and obtain cryptoassets. The core strategy involves the agent sending a request for cooperation to the domestic exchange office. This request invites the exchange to disclose whether Filip has an account, including an electronic wallet, data on this electronic wallet and data on the debtor's cryptoassets that are on the electronic wallet. If the exchange cooperates, the LEA can enforce the seizure of those assets and monetise them. However, a fundamental problem persists: the debtor's ability to dispose of the assets. An enforcement order might be served too late, or the data in the enforcement order may no longer correspond to the real balance on the debtor's electronic wallet.

Data from Licensed Enforcement Agents

As part of the research, we surveyed LEAs by sending a questionnaire through the Chamber of Licensed Enforcement Agents. As of this study's preparation date, 64 out of 145 active LEAs had completed the questionnaire. According to members of the Chamber, agents with no experience with cryptoassets were unlikely to complete the questionnaire.

Table 1. Experience of Enforcement Offices with Cryptoassets According to Length of Practice; author's own elaboration

Length of practice	No experience with enforcing cryptoassets	Cases with identified cryptoassets
10–19 years	24	4
20 years or more	23	2
5–9 years	10	0
Less than 5 years	1	0

Source: author's own elaboration.

More than 82% of respondents have been practising LEAs for more than 20 years, which ensures the high relevance and professional weight of their answers. As shown in Table 1, the results showed that 58 out of the 64 LEAs (over 90%) had never ordered or carried out any enforcement in which any cryptoassets were found. Of the remaining six LEAs who had directly

encountered cryptoasset enforcement in their practice, only one had dealt with multiple cases; the remaining five had dealt with only a few cases, and none had ever seized and subsequently monetised cryptoassets as part of these enforcement actions. The failures were primarily attributed to the assets being held with a foreign entity, the debtor not cooperating, or the lack of access to the account data.

It is also significant that 27 LEAs (more than 42% – see Figure 1) had encountered situations where the debtor had tried to conceal assets using cryptoassets, or where it was evident that the debtor owned cryptoassets but they could not be identified during the enforcement proceedings. The LEAs obtained this information through various means: from the creditor, from the debtor's bank account statements, or directly from the debtor, either through confirmation or through information shared on social media.

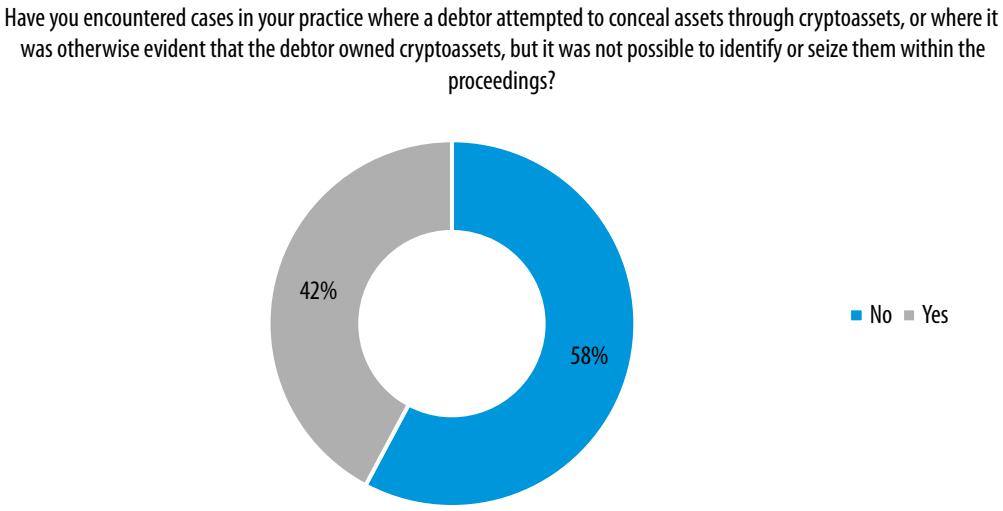


Figure 1. Cases Involving Debtors' Attempts to Conceal Assets via Cryptoassets
Source: author's own elaboration.

A total of 45 LEAs consider the current legal regulation to be entirely insufficient for the effective enforcement of enforcement title against cryptoassets. The remaining LEAs did not comment on the matter. The reasons for deeming the legal regulation to be insufficient are repeated and consist mainly of four key issues. First, there is the absence of specific legal regulations for the enforcement of cryptoassets. Second, there is a lack of effective tools for identifying and effectively sanctioning cryptoassets. Third, the partial anonymity of cryptocurrency wallets and the frequent use of foreign entities to purchase cryptoassets, which debtors then store them in, pose a challenge. Given these findings, more than 93% of LEAs expressed the need to introduce training, methodological support, or legislative changes in sanctioning digital assets in enforcement proceedings, as shown in Figure 2.

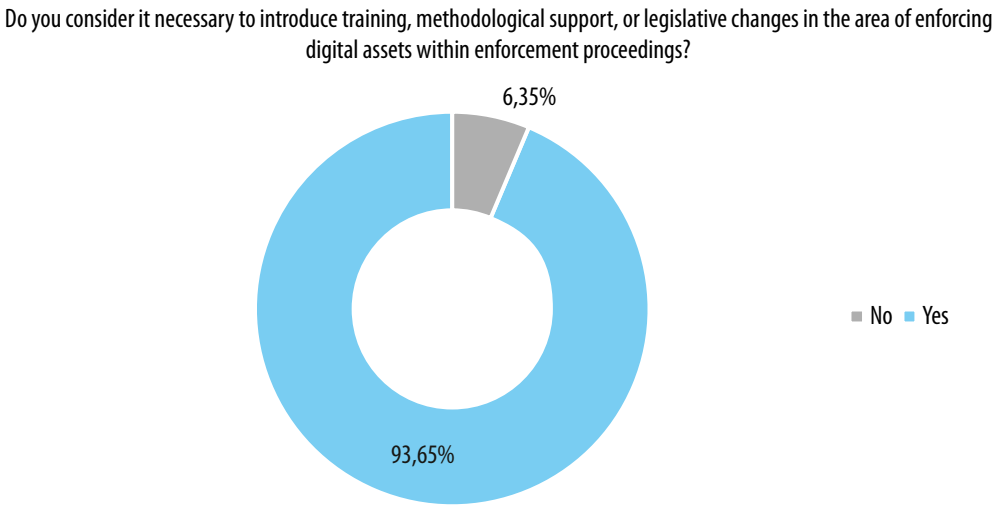


Figure 2. Perceived Need for Support and Legal Reforms in the Enforcement of Digital Assets
Source: author's own elaboration.

Insolvency Proceedings and Cryptoassets

In the Czech legal system, insolvency proceedings constitute a distinct legal process designed to satisfy creditors' claims while simultaneously protecting the insolvent debtor. In simplified terms, insolvency proceedings share objectives with enforcement proceedings namely, the identification, monetisation, and distribution of the debtor's assets among creditors although they differ in their procedural mechanisms. All the problematic aspects identified in connection with cryptoassets in enforcement proceedings are equally present in insolvency proceedings. The principal distinction lies in the position and authority of the insolvency administrator. In certain instances, the administrator is authorised to act on behalf of the debtor, allowing them to directly contact cryptocurrency exchanges, which are then obliged to cooperate (though this obligation applies primarily to domestic exchanges, not foreign entities). The insolvency administrator is further empowered to dispose of property freely and is not limited solely to auctions, as is the case in enforcement. This flexibility represents a considerable procedural advantage. Moreover, where the debtor fails to cooperate, for example, by withholding access to data to a crypto wallet or concealing the existence of assets, such conduct may lead to the failure of the insolvency proceedings, including the loss of eligibility for debt relief under Czech law. Given the substantial benefits of debt relief, the risk of forfeiting this option generally incentivises debtor cooperation.

In essence, however, all the substantive and procedural difficulties associated with cryptoassets in enforcement particularly issues of identification, access, and valuation also persist in insolvency proceedings.

Conclusion

This study has demonstrated that the enforcement of cryptoassets in the Czech Republic presents challenges of far greater complexity than those encountered in traditional enforcement proceedings. While enforcement against bank accounts or real estate operates within a clearly defined and predictable legal framework, cryptoassets continue to exist in a substantial legal and procedural vacuum. Their anonymity, technological opacity, decentralised structure, cross-border dimension, and the absence of a central authority collectively make debt recovery markedly more costly, time-consuming, and uncertain.

Although the Czech Civil Code recognises cryptoassets as intangible movable property, their practical enforcement is impeded by persistent ambiguities concerning the identification and location of digital wallets, the inability to compel debtors to disclose access credentials such as PIN codes or seeds, and the absence of standardised methods for valuation or transfer, particularly when assets are held on foreign exchanges.

Empirical evidence gathered from LEAs confirms that the issue is increasingly relevant in practice. Nonetheless, enforcement agents still lack the technical infrastructure and clear procedural methodology necessary for effective asset identification, seizure, and monetisation. Assets stored on foreign exchanges remain largely beyond the reach of domestic enforcement authorities, which are dependent on the voluntary cooperation of entities not subject to Czech jurisdiction. Likewise, the absence of a uniform valuation framework exacerbates uncertainty for both creditors and debtors.

Although some cryptoassets have already been monetised in public auctions, such procedures remain experimental and carry substantial risks arising from market volatility, settlement delays, and variable transaction fees. To minimise these risks, it is essential to establish rules that ensure fair valuation and procedural stability within the existing enforcement framework.

A sustained dialogue among legislators, legal scholars, practitioners, and technology experts is, therefore, crucial to developing procedures that reflect the technological realities of digital assets while safeguarding the legitimate interests of all parties. Without legislative intervention and institutional reform, cryptoassets will continue to represent an elusive and disproportionately costly form of property from which creditors cannot effectively satisfy their claims.

This gap in enforceability further confirms the broader risks identified in the literature on state sovereignty. The practical impossibility of securing assets held in private hardware wallets or on foreign exchanges effectively creates a safe haven for illicit financial flows. The Czech case thus illustrates a global paradox: while regulatory frameworks such as MiCA seek to standardise the market and establish harmonised rules for providers of services related to cryptoassets, the state's actual coercive authority remains limited not only by physical and technological barriers which in the digital sphere significantly weaken the state monopoly on the legitimate use of force but also by legal obstacles stemming from the absence of international cooperation among competent authorities. As a result, individuals may avoid state sanctions simply by shifting jurisdiction.

A functional legal framework must enhance cooperation with domestic and foreign crypto-exchange operators, particularly by obligating them to provide enforcement agents with verified data on account holders, balances, and transactions. Furthermore, it is necessary to develop dedicated enforcement instruments allowing for the freezing or blocking of digital wallets pursuant to an enforcement order, as well as to standardise valuation methods capable of reflecting extreme price fluctuations.

Implementing these measures would not only align legal practice with the technological evolution of financial markets but also enhance legal certainty for creditors while respecting the digital privacy of debtors. Ultimately, only the coordinated development of legislation, technical tools, and enforcement practice can transform cryptoassets from an inaccessible reservoir of value into an integral and enforceable component of modern legal systems both in the Czech Republic and across the EU.

The research was supported by the Czech Science Foundation Grant No. 24–12864S, titled 'Crypto Assets as a Threat to the Sovereign'.

References

Act No. 99/1963 Coll., Code of Civil Procedure, https://www.zakonyprolidi.cz/translation/cs/1963-99?langid=1033 (accessed: 9.05.2025).

Act No. 120/2001 Coll., Act on Bailiffs and Enforcement Activity (Enforcement Code) and on Amendments to Other Acts, https://www.zakonyprolidi.cz/translation/cs/2001-120?langid=1033 (accessed: 9.05.2025).

Act No. 253/2008 Coll., Act on Certain Measures against the Legalization of Proceeds of Crime and Terrorist Financing, https://www.zakonyprolidi.cz/translation/cs/2008-253?langid=1033 (accessed: 9.05.2025).

Act No. 89/2012 Coll., Civil Code, https://www.zakonyprolidi.cz/translation/cs/2012-89?langid=1033 (accessed: 9.05.2025).

Act No. 286/2021 Coll., Act amending Act No. 99/1963 Coll., the Code of Civil Procedure, as amended, Act No. 120/2001 Coll., on licenced enforcement agents and enforcement activities (the Code of Enforcement) and on amendments to other acts, as amended, and some other acts, https://www.zakonyprolidi.cz/cs/2021-286 (accessed: 9.05.2025).

Act of 17 November 1964 – Code of Civil Procedure, as amended, https://eli.gov.pl/api/acts/DU/1964/297/text/O/D19640297.pdf (accessed: 9.05.2025).

Cardao-Pito, T. (2025), *Can cryptocurrency exchanges threaten sovereign states? Lessons and hypotheses from the Binance case*, "Journal of Financial Crime", 32 (5), pp. 1030–1040, https://doi.org/10.1108/JFC-10-2024-0336

Český statistický úřad (2025), *Průměrné mzdy – 4. čtvrtletí 2024*, https://csu.gov.cz/rychle-informace/prumerne-mzdy-4-ctvrtleti-2024 (accessed: 11.04.2025).

Daňhel, R. (2025), *Aukční vyhláška: Č. j.: MSP-76/2025-OIM-SML2/1*, https://www.nabidkamajetku.gov.cz/api/Property/Attachment/2be8044b-02f7-421c-8dcf-b60ace2a25ef (accessed: 9.05.2025).

Dupuis, D., Gleason, K. (2020), *Money laundering with cryptocurrency: open doors and the regulatory dialectic*, "Journal of Financial Crime", 28 (1), pp. 60–74, https://doi.org/10.1108/JFC-06-2020-0113

Dvořák, J., Švestka, J., Zuklínová, M. (2016), *Občanské právo hmotné. 2. aktualizované a doplněné vydání*, Wolters Kluwer, Prague.

Erp, S. (2022), *Komorní listy: Digitální aktiva… „fantomový dlužník"*, "Exekutorská komora České republiky", 12 (2), pp. 22–25.

Exekutorská komora České republiky (2025), *Počet fyzických osob v exekuci a další podrobnosti*, https://statistiky.ekcr.info/otevrena-data (accessed: 4.11.2025).

Ferreira, A., Sandner, P. (2021), *Eu search for regulatory answers to crypto assets and their place in the financial markets' infrastructure*, "Computer Law & Security Review", 43, 105632, https://doi.org/10.1016/j.clsr.2021.105632

Heyman, C.E.(R.) (2023), *A red flag checklist for cryptocurrency Ponzi schemes*, "Journal of Financial Crime", 31 (3), pp. 711–747, https://doi.org/10.1108/JFC-05-2023-0118

Hrabčák, L., Štrkolec, M. (2024), *EU Regulation of the Crypto-Assets Market*, "Białostockie Studia Prawnicze", 29 (1), pp. 27–45, https://doi.org/10.15290/bsp.2024.29.01.02

Institut prevence a řešení předlužení (2025a), *Exekuce*, https://www.institut-predluzeni.cz/mapy-a-statistiky/exekuce/ (accessed: 11.04.2025).

Institut prevence a řešení předlužení (2025b), *Podíl osob v exekuci po krajích (Q4 2024)*, https://mapazadluzeni.cz/?g=kraj&v1=podil_osob_v_exekuci&v1p=2024-Q4 (accessed: 13.04.2025).

Institut prevence a řešení předlužení (2025c), *Podíl osob v exekuci po krajích (2022, Q4 2023, Q4 2024 a Q1 2025)*, https://mapazadluzeni.cz/?g=kraj&v1=podil_osob_v_exekuci&v1p=2022&v1p=2023-Q4&v1p=2024-Q4&v1p=2025-Q1&vis=table (accessed: 15.04.2025).

Institut prevence a řešení předlužení (2025d), *Podíl osob s více exekucemi po krajích (2022, Q4 2023, Q4 2024 a Q1 2025)*, https://mapazadluzeni.cz/?g=kraj&v1=podil_exekvovanych_s_2_a_vice_exekucemi&v1p=2022&v1p=2023-Q4&v1p=2024-Q4&v1p=2025-Q1&vis=table (accessed: 10.04.2025).

Irwin, A.S.M., Milad, G. (2016), *The use of crypto-currencies in funding violent jihad*, "Journal of Money Laundering Control", 19 (4), pp. 407–425, https://doi.org/10.1108/JMLC-01-2016-0003

Jones, H. (2023), *EU urges others to copy its rules for cryptoassets*, https://www.reuters.com/technology/eu-urges-others-copy-its-rules-cryptoassets-2023-04-19/ (accessed: 28.10.2025).

Judgment of the Supreme Administrative Court of 6 March 2018, file reference II FSK 488/16, https://www.inforlex.pl/dok/tresc,NSA.2018.001.100009851,Wyrok-NSA-z-dnia-6-marca-2018-r-sygn-II-FSK-488-16.html (accessed: 28.10.2025).

Kabra, S., Gori, S. (2023), *Drug trafficking on cryptomarkets and the role of organized crime groups*, "Journal of Economic Criminology", 2, 100026, https://doi.org/10.1016/j.jeconc.2023.100026

Kaliský, B. (2018), *Bitcoin a ti* druzí: nepostradatelný *průvodce světem kryptoměn*, IFP Publishing, Prague.

Kohajda, M., Moravec, J. (2021), *Legal Issues of Stablecoins*, "Daně a finance", 28 (1–4), pp. 93–98, https://www.researchgate.net/publication/357428892_Legal_Issues_of_Stablecoins (accessed: 19.06.2025).

Kozieł, M. (2025), *New Regulation of Crypto-Assets in the European Union as an Opportunity and a Threat for Entrepreneurs*, [in:] S. Kot, B. Khalid, A. ul Haque (eds.), *New Challenges of the Global Economy for Business Management*, Springer Proceedings in Business and Economics, Singapore, pp. 791–805, https://doi.org/10.1007/978-981-96-4116-1_50

Mackenzie, S. (2024), *Crypto collapse: the cult of personality and the normalisation of fraud in FTX and Celsius*, "Journal of Financial Crime", 32 (2), pp. 288–303, https://doi.org/10.1108/JFC-01-2024-0054

Maume, P. (2023), *The Regulation on Markets in Crypto-Assets (MiCAR): Landmark Codification, or First Step of Many, or Both?*, "European Company and Financial Law Review", 20 (2), pp. 243–275, https://doi.org/10.1515/ecfr-2023-0014

Morton, T. (2020), *The Future of Cryptocurrency: An Unregulated Instrument in an The Future of Cryptocurrency: An Unregulated*, "International Journal of Social Sciences", 4 (1), pp. 555–570, https://lawecommons.luc.edu/lucilr/vol16/iss1/8 (accessed: 19.06.2025).

Nabilou, H. (2019), *How to regulate bitcoin? Decentralized regulation for a decentralized cryptocurrency*, "International Journal of Law and Information Technology", 27 (3), pp. 266–291, https://doi.org/10.1093/ijlit/eaz008

Ocampo, D.G., Branzoli, N., Cusmano, L. (2023), *Crypto, tokens and DeFi: navigating the regulatory landscape*, https://www.bis.org/fsi/publ/insights49.htm (accessed: 17.10.2025).

Regulation (EU) 2023/1113 of the European Parliament and of the Council of 31 May 2023 on information accompanying transfers of funds and certain crypto-assets and amending Directive (EU) 2015/849, https://eur-lex.europa.eu/eli/reg/2023/1113/oj/eng (accessed: 17.10.2025).

Regulation (EU) 2023/1114 of the European Parliament and of the Council of 31 May 2023 on markets in crypto-assets and amending Regulations (EU) No. 1093/2010 and (EU) No. 1095/2010 and Directives 2013/36/EU and (EU) 2019/1937. OJ L 150, 9 June 2023, https://eur-lex.europa.eu/eli/reg/2023/1114/oj/eng (accessed: 17.10.2025).

Takei, Y., Shudo, K. (2024), *Pragmatic Analysis of Key Management for Cryptocurrency Custodians*, [in:] *2024 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*, 27–31 May, Ireland, pp. 747–765, https://doi.org/10.1109/ICBC59979.2024.10634356

Tiwari, M., Lupton, C., Bernot, A., Halteh, K. (2024), *The cryptocurrency conundrum: the emerging role of digital currencies in geopolitical conflicts*, "Journal of Financial Crime", 31 (6), pp. 1622–1634, https://doi.org/10.1108/JFC-12-2023-0306

Van der Linden, T., Shirazi, T. (2023), *Markets in crypto-assets regulation: Does it provide legal certainty and increase adoption of crypto-assets?*, "Financial Innovation", 9 (1), https://doi.org/10.1186/s40854-022-00432-8

Wronka, C. (2021a), *Digital currencies and economic sanctions: the increasing risk of sanction evasion*, "Journal of Financial Crime", 29 (4), pp. 1269–1282, https://doi.org/10.1108/JFC-07-2021-0158

Wronka, C. (2021b), *Financial crime in the decentralized finance ecosystem: new challenges for compliance*, "Journal of Financial Crime", 30 (1), pp. 97–113, https://doi.org/10.1108/JFC-09-2021-0218

Xu, X., Weber, I., Staples, M. (2019), *Architecture for Blockchain Applications*, Springer, Cham, https://doi.org/10.1007/978-3-030-03035-3

Zetzsche, D.A., Arner, D.W., Buckley, R.P. (2020), *Decentralized Finance*, "Journal of Financial Regulation", 6 (2), pp. 172–203, https://doi.org/10.1093/jfr/fjaa010

Kryptoaktywa jako zagrożenie dla suwerenności państwa w obszarze egzekucji i niewypłacalności

Kryptoaktywa, jako nowatorska forma technologii finansowej, stanowią wyzwanie dla tradycyjnych ram prawnych, zwłaszcza ze względu na swój zdecentralizowany charakter oraz specyficzny sposób przechowywania i transferu. Ich pojawienie się wymaga ponownego przeanalizowania zasad regulacyjnych i mechanizmów ochrony praw uczestników rynku kryptoaktywów w środowisku, w którym decentralizacja oznacza brak scentralizowanej kontroli. W niniejszym artykule omówiono kryptoaktywa jako potencjalne zagrożenie

dla suwerenności państwa w obszarach egzekucji i niewypłacalności. Przeanalizowano wyzwania legislacyjne wynikające z rosnącej popularności kryptoaktywów oraz oceniono możliwość zastosowania tradycyjnych instrumentów prawa egzekucyjnego w kontekście tych nowych technologii.
W opracowaniu przedstawiono również wyniki badań empirycznych dotyczących czeskiego środowiska prawnego w szerszym kontekście teoretycznym, dotyczącym przestępstw finansowych i erozji władzy państwowej spowodowanej zdecentralizowanymi systemami finansowymi działającymi w różnych jurysdykcjach krajowych. Szczególną uwagę poświęcono technicznym cechom kryptoaktywów, ich klasyfikacji prawnej oraz praktycznym przeszkodom napotykanym w postępowaniach egzekucyjnych i upadłościowych, zwłaszcza w sytuacjach, gdy dłużnicy odmawiają lub nie są w stanie zapewnić dostępu do swoich aktywów cyfrowych.
Analiza uwzględnia również dostępne statystyki dotyczące postępowań egzekucyjnych i poddaje ocenie czeskie ramy prawne funkcjonowania kryptoaktywów, koncentrując się na ich wpływie na skuteczność procesów egzekucyjnych i upadłościowych. W badaniach wykorzystano zarówno metody pierwotne, jak i wtórne, w tym analizę prawną i techniczną, modelowanie rzeczywistych scenariuszy oraz badanie odpowiednich instrumentów prawnych.

Słowa kluczowe: Czechy, kryptowaluta, postępowanie egzekucyjne, niewypłacalność, ramy prawne

Comparative Economic Research. Central and Eastern Europe
Volume 29 Number 1, 2026
https://doi.org/10.18778/1508-2008.29.05

Fiscal Support, QE and Income-smoothing in European Banks during the COVID-19 Crisis

Małgorzata Olszak https://orcid.org/0000-0001-8920-5309
Associate Professor, University of Warsaw, Faculty of Management, Warsaw, Poland,
e-mail: ma.olszak@uw.edu.pl

Gracjan R. Bachurewicz https://orcid.org/0000-0002-1990-5390
Ph.D., University of Life Sciences in Poznań, Poznan, Poland, e-mail: gracjan.bachurewicz@gmail.com

Christophe Godlewski https://orcid.org/0000-0002-1391-1108
Professor, University of Strasbourg, Faculty of Law and Business, Strasbourg, France,
e-mail: godlewski@unistra.fr

Abstract

This study examines how fiscal and monetary policy responses to the COVID-19 crisis influenced banks' income smoothing through loan-loss provisions (LLPs) in the European Economic Area (EEA). Using a panel of 1,122 commercial banks from 29 countries between 2011 and 2020, we investigate whether the intensity of income smoothing varied with the scale of public support. Fiscal liquidity measures and the European Central Bank's quantitative easing (QE) under the Pandemic Emergency Purchase Programme (PEPP) serve as proxies for government and monetary interventions. The results show that both fiscal and monetary support reduced average LLP levels but simultaneously strengthened the link between earnings and provisioning, indicating increased income-smoothing behavior during the pandemic. This pattern reflects two complementary mechanisms: the crisis-severity channel, where larger policy interventions corresponded to deeper economic stress, and the moral-hazard channel, where public backstops expanded managerial discretion in provisioning. Overall, the findings suggest that large-scale stabilization policies mitigated credit risk and preserved financial stability but also encouraged more discretionary accounting behavior, underscoring a potential trade-off between crisis management and the transparency of banks' financial reporting.

Keywords: loan-loss provisions, income-smoothing, liquidity support
JEL: E44, E58, G21, G28

Funding information: National Science Centre (NCN) in Poland, decision No. 2019/35/B/HS4/02471.
The percentage share of the Authors in the preparation of the work is: M.O. – 33.33%, G.R.B. – 33.33%, C.G. – 33.33%.
Declaration regarding the use of GAI tools: Not used.
Conflicts of interests: None.
Ethical considerations: The Authors assure of no violations of publication ethics and take full responsibility for the content of the publication.
Received: 8.09.2025. Verified: 20.10.2025. Accepted: 29.01.2026

Introduction

Income smoothing refers to banks' discretionary use of loan-loss provisions (LLPs) to stabilize reported earnings over time. By adjusting provisions in response to profit fluctuations, managers can buffer earnings volatility and signal stability to markets. While this behavior is well-documented in earlier crises, evidence from the COVID-19 crisis remains limited. Unlike the 2008 Global Financial Crisis (GFC), the pandemic originated outside the financial system but triggered a severe real-economy shock, leading to unprecedented fiscal and monetary responses. This paper examines how these policy interventions affected the use of LLPs for income smoothing among commercial banks in the European Economic Area (EEA). Specifically, we test the **COVID-crisis smoothing hypothesis**, which predicts that public fiscal and monetary interventions increased banks' incentives to smooth earnings during the pandemic. In addition, we evaluate whether larger policy support packages were associated with a decline in LLP levels, reflecting improved borrower solvency and reduced expected credit losses.

Recent studies have explored the impact of the COVID-19 crisis on bank profitability, stock returns, and credit risk (Berger and Demirgüç-Kunt 2021; Demir and Danisman 2021; Duan et al. 2021; Elnahass et al. 2021; Silva et al. 2023), as well as on provisioning behavior (Degryse and Huylebroek 2023; Hansen, Charifzadeh, and Herberger 2024). However, few have analyzed whether the scale of public support fiscal or monetary altered banks' incentives for discretionary provisioning. Fiscal interventions, such as liquidity guarantees and monetary measures under the European Central Bank's (ECB) Pandemic Emergency Purchase Programme (PEPP), were concentrated in countries facing deeper economic downturns (Wieland 2022; Demirgüç-Kunt, Horváth, and Huizinga 2023). These measures may have affected provisioning through two mechanisms: the crisis-severity channel, reflecting higher credit risk and deeper reductions in earnings in harder-hit economies, and the moral-hazard channel, where policy backstops reduced market discipline and expanded managerial discretion.

Using an unbalanced panel of 1,122 EEA banks for the period 2011–2020, we test whether income smoothing during COVID-19 was linked to the magnitude of fiscal and monetary interventions. We also assess whether the mitigating effect of public support on LLP levels, found in publicly traded banks (Degryse and Huylebroek 2023), applies generally to commercial banks. Fiscal support is proxied by government liquidity programs, and monetary easing is proxied by ECB asset purchases under PEPP (QE PEPP). Employing a random-effects model with bank-clustered robust errors, we find that both fiscal and monetary support reduced average LLP levels but simultaneously intensified the link between earnings and provisioning indicating stronger income smoothing in countries that received larger public support.

This study contributes to the literature in three ways. First, it integrates crisis-severity and moral-hazard channels to explain how stabilization policies shape banks' financial reporting behavior. Second, it extends evidence from Degryse and Huylebroek (2023) by including unlisted banks and explicitly modeling income smoothing, not just LLP levels. Finally, it situates fiscal and monetary support as key cross-country determinants of provisioning behavior, contributing to the ongoing debate on the unintended effects of large-scale policy interventions on the transparency of banks' financial reporting.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature and develops our hypotheses. Section 3 details our dataset and methodology. Section 4 presents the findings and robustness checks. Section 5 concludes.

Literature review and hypotheses

The use of loan loss provisions as a discretionary instrument for income smoothing is well established in the banking literature (Fonseca and González 2008; El Sood 2012; Bouvatier, Lepetit, and Strobel 2014; Skała 2020, 2021; Di Fabio, Ramassa, and Quagli 2021). While LLPs are intended to capture expected credit losses, they also serve as a tool for managing reported earnings and maintaining stability over time, particularly during periods of financial stress (Curcio, De Simone, and Gallo 2017; Ozili and Thankom 2018).

At the bank level, governance structures, ownership types, and market pressures shape the degree of managerial discretion in provisioning (Bouvatier, Lepetit, and Strobel 2014; Fan et al. 2019; Skała 2021). At the country level, regulation quality, investor protection, and accounting standards determine the transparency and prudential use of LLPs (Fonseca and González 2008; Gebhardt and Novotny-Farkas 2011; Olszak et al. 2025).

During crisis periods, provisioning behavior becomes more complex. Empirical studies find that downturns amplify the procyclicality of LLPs and increase incentives for income smoothing (El Sood 2012; Curcio, De Simone, and Gallo 2017; Ozili and Thankom 2018; Skała 2021). Banks tend to use discretionary provisions to mitigate earnings volatility, maintain capital ratios, and signal financial soundness to markets.

Existing research has also examined how crisis periods influence income smoothing. Most studies have focused on the Global Financial Crisis (GFC) (El Sood 2012; Curcio, De Simone, and Gallo 2017; Ozili and Thankom 2018; Pinto and Ng Picoto 2018; Kim, Kim, and Lee 2019; Simper, Dadoukis, and Bryce 2019; Di Fabio, Ramassa, and Quagli 2021). A large body of evidence confirms that crises – particularly the GFC – significantly affected the use of LLPs for income smoothing (Curcio, De Simone, and Gallo 2017; Ozili and Thankom 2018; Pinto and Ng Picoto 2018; Simper, Dadoukis, and Bryce 2019; Di Fabio, Ramassa, and Quagli 2021; Skała 2021).

Two Channels Linking Public Support and Bank Behavior during the COVID-19 Crisis

The COVID-19 crisis had a distinct nature, as it originated outside the financial system but caused profound economic disruptions. Its effects on banking activities depended largely on the severity of the pandemic's macroeconomic impact. Countries facing deeper recessions and higher corporate distress experienced stronger pressure on banks' asset quality and profitability. The severity of the crisis can be approximated by the scale of fiscal and monetary support measures aimed at economic recovery (Demirgüç-Kunt, Pedraza, and Ruiz-Ortega 2021). In Europe, they included government liquidity injections, borrower relief programs, and monetary easing. Such interventions helped cushion the shock to bank performance

and stabilize financial markets but also changed the relationship between economic downturns and provisioning decisions (Degryse and Huylebroek 2023; Nguyen et al. 2023).

Recent empirical evidence confirms that large-scale fiscal and monetary interventions mitigated immediate credit losses while simultaneously altering banks' incentives for discretionary provisioning, particularly in countries most affected by the pandemic (Degryse and Huylebroek 2023). These findings support the view that while public backstops can stabilize the banking sector in the short run, they may distort the risk–provisioning nexus by relaxing market discipline and allowing for greater managerial discretion.

The Crisis-Severity Channel

The first mechanism linking public support and bank behavior operates through the crisis-severity channel. The magnitude of fiscal and monetary interventions reflects the depth of the macroeconomic shock. Larger government spending and central bank interventions were concentrated in countries most severely hit by the pandemic, which also faced heightened credit risk and uncertainty.

Recent cross-country evidence supports this interpretation. Degryse and Huylebroek (2023) document that greater fiscal support – particularly through direct transfers and guarantees – was associated with lower LLP levels among listed banks, implying that public interventions improved borrower solvency and reduced provisioning needs. However, their study covers only publicly traded institutions and does not fully encompass the EEA banking sector, where smaller and unlisted banks may react differently to policy stimuli. Nguyen et al. (2023) find that banks significantly increased discretionary loan-loss provisions in the early stages of the pandemic but subsequently reduced overall LLP levels as fiscal and monetary support stabilized borrower solvency and restored economic confidence. Similarly, Allini et al. (2025) show that during downturns, banks actively use LLPs for earnings management, particularly under heightened uncertainty, confirming the procyclical and discretionary nature of provisioning in times of stress.

In Europe, the forward-looking design of IFRS 9 amplified this dynamic. As demonstrated by Hansen, Charifzadeh, and Herberger (2024), expected credit loss models increased the sensitivity of LLPs to macroeconomic fluctuations, making banks' provisioning behavior more responsive to the depth of the downturn and the accompanying policy interventions. Complementary evidence from Augeraud-Véron, Boungou, and Gupta (2025) indicates that better-capitalized banks recovered faster from pandemic shocks, suggesting that fiscal and monetary responses improved resilience but did not eliminate cyclical pressures on provisioning.

Overall, the scale of fiscal and monetary support captured both the intensity of the crisis and the extent of public stabilization efforts. In countries with stronger government and central bank interventions, banks faced heightened incentives to smooth earnings in response to volatility, while average provisioning levels declined due to policy-driven improvements in credit conditions (Degryse and Huylebroek 2023).

The Moral-Hazard Channel

The second mechanism operates through the moral-hazard channel, emphasizing behavioral adjustments to extensive public support. When governments and central banks implement large-scale liquidity programs, credit guarantees, and asset purchases, banks may perceive a reduced risk of insolvency and weaker market discipline. This perception can increase managerial discretion and encourage opportunistic income-smoothing practices.

Evidence from earlier crises and recent studies supports this concern. For example, Allini et al. (2025) highlight that in periods of downturn and abundant policy intervention, banks are more likely to manipulate LLPs to stabilize reported earnings. Similarly, Ma and Lan (2025) find that monetary policy shocks influence banks' provisioning behavior, with looser conditions reducing the sensitivity of LLPs to credit risk. These findings imply that accommodative policies while stabilizing the financial system – may unintentionally promote greater discretion in provisioning decisions.

Fiscal guarantees, borrower relief programs, and quantitative easing under the ECB's PEPP effectively cushioned the immediate impact of the pandemic on credit risk. However, they may also have encouraged banks to delay loss recognition or strategically use LLPs to manage earnings. Consequently, in economies with higher levels of fiscal and monetary support, banks may exhibit both lower LLP ratios, reflecting improved borrower solvency, and stronger income-smoothing behavior, driven by increased managerial discretion.

Hypotheses Development

Both fiscal support and quantitative easing (QE) under PEPP were concentrated in countries most severely affected by the pandemic and linked to heightened economic uncertainty (Berger and Demirgüç-Kunt 2021). Consequently, the extent of income smoothing is expected to vary with the scale of fiscal and monetary support, which simultaneously reflects the severity of the crisis and the potential for moral hazard. Accordingly, we propose the following hypotheses regarding income smoothing:

Hypothesis H1. The scale of public fiscal support is positively associated with income smoothing through LLPs during the COVID-19 crisis.

Hypothesis H2: The scale of monetary support (QE under PEPP) is positively associated with income smoothing through LLPs during the COVID-19 crisis.

Consistent with Degryse and Huylebroek (2023), who find that greater policy intervention reduced provisioning needs while maintaining managerial flexibility in earnings management, we also expect that public support will be linked to the levels of loan-loss provisions:

Hypothesis H3: Higher overall public support fiscal and monetary is associated with lower levels of LLPs.

Methods and data description

Model of loan loss provisions

Our baseline model describes links between LLPs of bank *i* at time *t* in country *c*. It is based on several previous research studies, including Fonseca and González (2008), Skała (2020; 2021), and Olszak et al. (2025), with modifications as in Beatty, Ke, and Petroni (2002), Fan et al. (2019) and Di Fabio et al. (2021). To empirically evaluate our hypothesis H1 that the intensity of income-smoothing during the coronavirus pandemic crisis depends on the fiscal and monetary response (Policy response), we use Equation 1 below:

$$LLP_{i,c,t} = \alpha + \beta_1 ProfitBPT_{i,c,t} + \beta_2 \left(ProfitBPT_{i,c,t} \times Crisis \times PolicyResponse\right) + \beta_3 PolicyResponse + \delta \times BSOCV_{i,c,t} + \mu_i + \nu_{i,t}, \quad (1)$$

where $LLP_{i,c,t}$ is the ratio of loan loss provisions to total assets for bank i in country c and year t; μ_i captures unobserved, time-invariant bank-specific heterogeneity, and $\nu_{i,t}$ is the idiosyncratic error term.

The key coefficient of interest, β_2, captures how income smoothing (proxied by the sensitivity of LLPs to pre-provision earnings) varies with the scale of fiscal or monetary support during the COVID-19 crisis. The variable *PolicyResponse* represents the intensity of government or central bank interventions. Fiscal support is measured as the ratio of total liquidity assistance to GDP, while monetary support corresponds to the share of asset purchases under PEPP relative to total government debt. Higher values of these ratios indicate both greater crisis severity and more extensive stabilization measures.

A positive β_2 would suggest that banks in countries with larger policy interventions exhibited stronger income smoothing, consistent with both the **crisis-severity channel** (heightened macroeconomic stress leading to greater earnings management) and the **moral-hazard channel** (reduced market discipline encouraging discretionary provisioning). Conversely, a negative β_2 would imply that expansive fiscal or monetary support dampened smoothing behavior, possibly by improving borrower solvency and reducing credit risk.

The coefficient β_3 reflects the direct effect of public interventions on the level of LLPs. Following Degryse and Huylebroek (2023), we expect fiscal measures to be negatively related to LLPs, as government support to non-financial borrowers mitigated loan impairment risk. For monetary policy (PEPP), the expected sign is also negative if quantitative easing alleviated liquidity stress and corporate debt burdens.

The vector $BSOCV_{i,c,t}$ includes standard bank-specific and macroeconomic controls commonly used in LLP studies (e.g., Fonseca and González 2008; Skała 2021; Olszak et al. 2025): ΔLoans – annual rate of loans growth; LLR – loan loss reserve; CapRATIO – capital funds divided by total assets; Loans – loans to total assets; Bank Size – natural logarithm of total assets; NPL – non-performing loans divided by gross loans; Unemployment – unemployment rate; GDPG – real GDP growth rate; Crisis – a dummy variable equal to 1 for 2020, which captures the pandemic shock.

This model design allows us to isolate the moderating effect of fiscal and monetary policy on income smoothing through LLPs, which is consistent with the theoretical expectations derived from both the crisis-severity and moral-hazard channels.

Endogeneity and estimation method

To address potential endogeneity, several preventive measures are implemented. First, to reduce the risk of measurement error, variable definitions for both dependent and explanatory variables follow standard practice in the LLP literature. We also include all banks available in the Orbis database and winsorize variables at the 1st and 99th percentiles to mitigate the influence of outliers. Second, to minimize omitted variable bias, we employ a specification widely used in prior loan loss provisioning research (Fonseca and González 2008; Olszak et al. 2018; Fan et al. 2019; Di Fabio et al. 2021; Skała 2021), thereby ensuring consistency with established empirical frameworks. Third, to limit simultaneity bias between LLPs and profitability measures, income statement items are normalized by lagged total assets. Since our unbalanced panel includes bank-level variables that may be correlated over time, we further control for potential autocorrelation and heteroskedasticity by applying robust standard errors clustered at the bank level.

Our primary estimation method is the random-effects (RE) model with bank-clustered robust standard errors. This choice is justified on both theoretical and statistical grounds. The COVID-19 crisis constitutes an exogenous macroeconomic shock, while country-level variables such as fiscal and monetary policy measures are exogenous to individual bank operations. The RE estimator is also suitable for our data structure, as it enables the inclusion of time-invariant country-level variables that would be absorbed by fixed effects.

Following Mundlak (1978) and Baltagi (2005), the RE specification assumes that all regressors are exogenous with respect to unobserved individual effects. In our context, certain bank-specific factors may be endogenous to LLPs, whereas macroeconomic indicators, fiscal and monetary policy responses, and institutional characteristics can reasonably be treated as exogenous. Based on standard specification diagnostics – the Hausman test, Breusch-Pagan Lagrangian multiplier test, and the robust Hausman test – we find no evidence of correlation between individual effects and regressors. Accordingly, the random-effects estimator with bank-clustered robust standard errors is adopted (Bell and Jones 2015; Bell, Fairbrother, and Jones 2018).

This estimation strategy enables direct testing of the hypotheses formulated in Section 2.2, linking banks' income-smoothing behavior to the scale of fiscal and monetary support during the COVID-19 pandemic.

Data description

Bank level and macroeconomic data

We compile data from multiple sources. Bank-level variables are drawn from Bank Orbis Focus, which comprises annual balance sheet and income statement information for over 1,000 banks (6,835 observations) across 29 European Economic Area countries between 2011 and 2020. The initial dataset covered more than 2,000 banks and 16,000 observations; to mitigate the influence of extreme values, variables are winsorized at the 1st and 99th percentiles. Due to the limited

availability of loan loss reserves (LLR) and non-performing loans (NPL), the final sample includes 1,122 banks and ends in 2020, focusing on the year when the COVID-19 pandemic shock was the most severe (see Table 1).

We must also admit that some banks in non-euro EEA countries applied LLPs to account for potential legal claims related to CHF-denominated mortgage loans (e.g., in Poland since 2019). These provisions, initially intended to address legal and reputational risks, were subsequently treated as an additional safety buffer during the pandemic. This practice may have temporarily increased reported resilience and reduced provisioning volatility, yet it also complicates cross-country comparability. In particular, pre-existing legal risk provisions may have interacted with pandemic-related adjustments, influencing the observed relationship between LLPs and fiscal or monetary policy responses.

As our objective is to examine the influence of country-specific characteristics on income smoothing, we use unconsolidated data to ensure that financial indicators reflect domestic rather than consolidated group effects. Macroeconomic variables – unemployment rate and GDP growth – are sourced from the International Monetary Fund's World Economic Outlook database.

Fiscal and monetary policy support data

The most comprehensive source of fiscal support data during the COVID-19 pandemic is the IMF's Fiscal Monitor Database of Country Fiscal Measures in Response to the COVID-19 Pandemic (Niermann and Pitterle 2021). This database summarizes key fiscal measures announced or implemented by selected economies in response to the crisis, classifying them into three categories with distinct short- and long-term budgetary implications (IMF 2021): (i) additional spending or one-off tax measures; (ii) tax deferrals; and (iii) guarantees or liquidity support to firms in financial distress.

Our analysis focuses on the third category. Fiscal support, primarily in the form of liquidity guarantees, loan moratoria, and direct subsidies to the non-financial corporate sector, was designed to sustain firm solvency and household income during the lockdown-induced recession. Larger fiscal packages were implemented in countries that faced more severe pandemic-related output losses and higher business vulnerability. Consequently, the scale of fiscal support reflects both the depth of the crisis and the extent of government intervention aimed at stabilizing credit markets.

From a banking perspective, fiscal transfers and guarantees directly improved borrower repayment capacity and reduced expected credit losses, thereby lowering LLP levels (Degryse and Huylebroek 2023). However, as these policies softened the link between actual credit risk and provisioning, they may also have amplified income-smoothing behavior, as managers exercised greater discretion to maintain stable earnings in an uncertain environment. Such measures directly influence banks' credit portfolio quality by reducing firm defaults, thereby affecting loan loss provisions and profitability. Fiscal support is proxied by liquidity support as a share of GDP (hereafter, **government fiscal support level**). On average, liquidity support in EEA countries amounted to over 13% of GDP, with substantial cross-country variation (standard deviation: 10.61%) (see Table 1).

In parallel, the ECB launched PEPP, a quantitative easing measure designed to counter severe disruptions in monetary policy transmission and the economic outlook (Demirgüç-Kunt, Horváth, and Huizinga 2023). Initially set at €750 billion, PEPP was later expanded to €1850 billion – equivalent to 15.4% of 2019 Euro Area GDP (Wieland 2022). Eligible private debt instruments were euro-denominated, investment-grade securities issued by non-bank firms in the euro area. Large-scale purchases of government securities under PEPP, together with those by national central banks, effectively monetized a substantial share of the pandemic-induced increase in public debt (Wieland 2022). In contrast to government interventions, PEPP represented an extraordinary monetary intervention aimed at restoring monetary policy transmission and preventing financial fragmentation across the euro area (European Central Bank 2020). The ECB deliberately applied flexibility in asset purchases, allocating a disproportionate share to countries experiencing stronger financial and economic distress (e.g., Italy, Spain, and Greece). PEPP thus served as both a stabilization mechanism and an indicator of crisis severity, as larger purchases were concentrated in economies under greater pressure. By improving liquidity in sovereign and corporate bond markets and lowering borrowing costs, PEPP reduced immediate market stress for banks but may also have encouraged moral hazard, as perceived credit and funding risks declined. We assess PEPP's role using the share of net PEPP purchases in government debt as of 2020 for each euro area country. The average share was 6.9%, with notable dispersion (standard deviation: 1.37%).

Table 1. Variable names, definitions, mean values and data sources

Variable	Definition	Mean	#Obs	#Banks	Source
Fiscal and liquidity support variables:					
Fiscal support level	Covid-19 Liquidity Support as a % of GDP	13.13	1122	1122	IMF
QE PEPP	ECB Net PEPP purchases as a % of government debt purchased	6.90	787	787	ECB, Eurostat.
Fiscal support: Equity injections and loans	COVID19 Liquidity Equity and Loan as a % of GDP	1.47	1122	1122	IMF
Fiscal support - guarantees	COVID19Liquidity Guarantees as a % of GDP	11.95	1122	1122	IMF
Country level PEPP to total PEPP	COVID19 ECB net purchases % of Total PEPP	13.31	787	787	ECB, Eurostat.
Bank-level and other control variables					
LLP	LLP/ lagged total assets (in %)	0.23	6835	1122	BankOrbisFocus
ProfitBPT	(Profit before taxes and LLP)/lagged total assets (in %)	1.36	6835	1122	BankOrbisFocus
ΔLoans	Loans growth rate (in %)	4.03	6835	1122	BankOrbisFocus
LLR	LLR/total assets (in %)	2.32	6835	1122	BankOrbisFocus
CapRATIO	Total capital/total assets (in %)	20.53	6835	1122	BankOrbisFocus
Loans	Loans/total assets (in %)	57.58	6835	1122	BankOrbisFocus
Bank Size	ln(Total assets)	14.80	6835	1122	BankOrbisFocus
NPL	Nonperforming loans / Total gross loans (in %)	6.73	6835	1122	BankOrbisFocus
Unemployment	unemployment rate	8.00	6835	1122	WEO, IMF

Variable	Definition	Mean	#Obs	#Banks	Source
GDPG	real GDP growth rate	1.08	6835	1122	WEO, IMF
Crisis	Dummy = 1 in the COVID-19 crisis period	0.10	1122	1122	Authors' own elaboration

Source: authors' elaboration using the datasets referred to in the table.

Figure 1 illustrates the substantial cross-country variation in fiscal liquidity support implemented during the COVID-19 pandemic across the EEA. The magnitude of fiscal interventions varied widely – from over 35% of GDP in Italy and 27.8% in Germany, to below 3% in Ireland, Austria, and Croatia – indicating pronounced asymmetry in governments' fiscal capacities and policy responses. The European Union (EU) average amounted to approximately 8% of GDP, with notable regional patterns: Central and Eastern European (CEE) countries provided smaller packages (around 5% of GDP), reflecting more limited fiscal space, while euro area members implemented larger interventions (around 9% of GDP) supported by EU-level mechanisms and stronger fiscal buffers. In line with the crisis-severity channel, these differences capture both the unequal macroeconomic impact of the pandemic and the varying ability of governments to stabilize the financial sector. Countries with higher fiscal support generally experienced more severe pandemic shocks, prompting stronger countercyclical measures. From a banking perspective, such fiscal interventions likely reduced expected credit losses and, consistent with Degryse and Huylebroek (2023), contributed to lower LLP levels. However, the scale of fiscal aid also shaped banks' reporting behavior: extensive public support may have softened market discipline and created conditions conducive to income smoothing, as managers exercised greater discretion to maintain stable earnings under uncertainty.

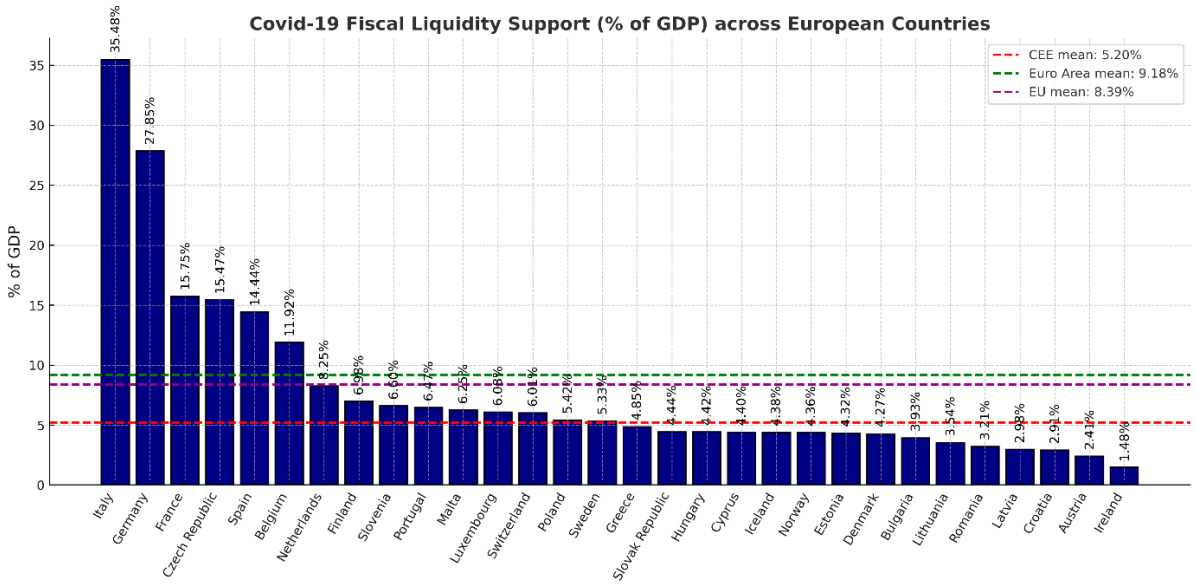


Figure 1. The share of the COVID-19 crisis fiscal liquidity support targeted at non-financial firms (as a % of GDP) in EEA countries

Source: authors' elaboration using IMF Fiscal Monitor: Database of Country Fiscal Measures in Response to the COVID-19 CRISIS Pandemic (IMF 2021).

Figure 2 presents the distribution of PEPP purchases across euro area countries, measured as a share of national government debt. The euro area average stood at approximately 6.9%, represented by the horizontal dashed line. The highest relative support under PEPP was observed in the Netherlands, Slovakia, and Slovenia (each around 10%), followed by Lithuania (9%), Germany and Luxembourg (8%). In contrast, Malta and Estonia recorded the lowest ratios (4%), while Belgium, France, Italy, and Portugal remained close to or below the euro area average. This pattern reflects the targeted nature of monetary intervention under PEPP, which was implemented with flexibility to direct purchases toward countries experiencing greater financial and economic stress. As such, higher PEPP allocations signal greater crisis severity and the ECB's effort to prevent market fragmentation and support credit flows in vulnerable economies. Within the framework of this study, the scale of PEPP purchases represents a complementary dimension of public intervention capturing the monetary policy response to crisis intensity and serves as an additional determinant of banks' provisioning and income-smoothing incentives. In line with the moral-hazard channel, extensive QE support may have reduced perceived credit and liquidity risk, encouraging managerial discretion in the use of LLPs for earnings management.

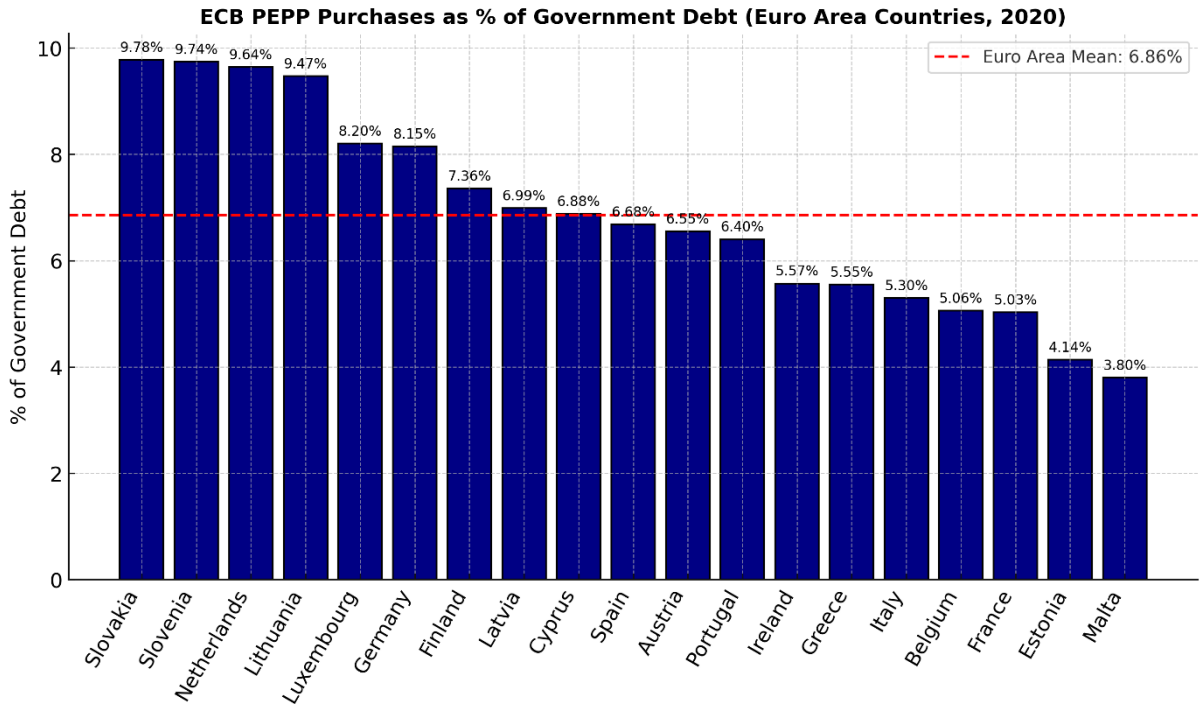


Figure 2. The QE via PEPP (as a % of total government debt) during the COVID-19 crisis in Euro Area countries
Source: Eurostat, ECB, authors' calculations.

Empirical results of the role of fiscal and monetary support

Table 2 presents the random-effects estimates that link fiscal and monetary interventions to banks' income-smoothing behavior during the COVID-19 crisis. The coefficient for *ProfitBPT* is positive and highly significant, confirming that banks used LLPs to stabilize earnings,

which is consistent with prior European evidence (Fonseca and González 2008; Skała 2021; Di Fabio et al. 2021).

The interaction *ProfitBPT* × *Crisis* × *Fiscal support* is positive and significant (0.005, $p < 0.01$), supporting H1 and showing that income smoothing intensified in countries with larger fiscal packages – averaging 13.1% of GDP (Table 1). This supports the crisis-severity channel, as higher fiscal spending reflected deeper economic distress and greater incentives for banks to buffer earnings volatility. The negative direct effect of fiscal support (–0.006, $p < 0.01$) confirms H3, indicating that fiscal measures lowered overall LLP levels by improving borrower solvency and credit quality, consistent with Degryse and Huylebroek (2023).

The interaction *ProfitBPT* × *Crisis* × *QE PEPP* is also positive and significant (0.011, $p < 0.05$), supporting H2. This suggests that the ECB's PEPP amplified income-smoothing behavior by easing funding pressures and enhancing banks' ability to manage earnings. At the same time, the negative coefficient on *QE PEPP* (–0.018, $p < 0.01$) reveals that monetary easing substantially reduced LLP levels, as stated in H3. This suggests that while QE improved liquidity and reduced expected credit losses, it also increased managerial discretion over provisioning decisions – reflecting a moral hazard effect. Thus, the liquidity benefits of PEPP simultaneously stabilized balance sheets and encouraged more flexible income-smoothing practices.

Comparatively, the marginal effect of monetary easing on income smoothing (0.011) is about twice as large as that of fiscal support (0.005), suggesting that QE provided greater scope for discretionary provisioning. Overall, the results reveal a dual effect of public interventions: they mitigated credit risk and stabilized banks (crisis-severity channel) but also fostered moral hazard by encouraging greater discretion in LLP use.

The results highlight an important trade-off between stabilization and prudential transparency in bank reporting. While large-scale fiscal and monetary interventions successfully reduced systemic risk, they may have indirectly encouraged income-smoothing practices that obscure the true timing of credit losses. These findings emphasize the need for supervisors to closely monitor provisioning behavior during and after crisis-related support programs, particularly in jurisdictions where public interventions were most extensive.

Table 2. Crisis-induced income smoothing–the role of fiscal support and the QE PEPP policy

Dependent variable: LLP	Governments' fiscal support level (as s % of GDP)	The ECB Pandemic Emergency Purchase Program (as a % of government debt purchased)
	1	2
ProfitBPT	0.194***	0.195***
	(0.023)	(0.023)
ProfitBPT × **Crisis × Fiscal support**	**0.005*** **	
	(0.002)	
ProfitBPT × **Crisis × QE PEPP**		**0.011****
		(0.006)

Dependent variable: LLP	Governments' fiscal support level (as s % of GDP)	The ECB Pandemic Emergency Purchase Program (as a % of government debt purchased)
	1	2
Fiscal support	−0.006***	
	(0.001)	
QE PEPP		−0.018***
		(0.005)
ΔLoans	−0.001	−0.001
	(0.001)	(0.001)
LLR(t − 1)	0.002	0.003
	(0.014)	(0.014)
CapRATIO(t − 1)	0.001	0.001
	(0.001)	(0.001)
Loans	0.005***	0.005***
	(0.001)	(0.001)
Bank Size	0.002	0.002
	(0.008)	(0.008)
NPL	0.027***	0.027***
	(0.005)	(0.005)
Unemployment	0.048***	0.047***
	(0.006)	(0.006)
GDPG	−0.034***	−0.036***
	(0.004)	(0.004)
Constant	−0.705***	−0.694***
	(0.141)	(0.142)
R-squared	0.187	0.185
#Observations	6835	6835
#Banks	1122	1122

Notes: This table displays the tests of hypotheses H1, H2, and H3. *LLP* – loan loss provisions scaled by total assets from year *t* − 1. *ProfitBPT* – denotes income before taxes and loan loss provision scaled by total assets from year *t* − 1. *Fiscal support* – denotes government liquidity support to non-financial corporations and enterprises (in % of GDP); *QE PEPP* denotes the net levels of Pandemic Emergence Purchase Program delivered by ECB quantitative easing (in % of total government debt). Control variables are the same as in Table 2. Robust standard errors are included in brackets. The coefficients are estimated with a random effects estimator. *, **, *** denote significance levels of 10%, 5%, and 1%, respectively.

Source: authors' analysis.

Regarding the other control variables, we find support for the view that banks with bigger loan portfolios tend to set aside higher levels of loan loss provisions. We also find evidence for the procyclicality of LLPs denoted by a negative coefficient on GDPG and a positive coefficient

on Unemployment, in line with previous research (Fonseca and González 2008; Skała 2020; 2021; Olszak et al. 2025). The positive coefficient on NPL further suggests that higher non-performing loan ratios are associated with greater provisioning needs, reflecting the credit risk sensitivity of LLPs. This indicates that a substantial portion of LLPs represents justified, non-discretionary adjustments for realized or anticipated credit losses.

Sensitivity analysis

To assess the robustness of our main findings and hypotheses H1–H3, we perform several sensitivity analyses that incorporate additional liquidity controls and alternative measures of fiscal and monetary support. Liquidity conditions are especially relevant in crisis periods, as they can influence provisioning behavior and banks' capacity to absorb shocks.

Columns (1)–(2) of Table 3 introduce the Loans-to-Deposits ratio (LtD) and the Liquidity Ratio (liquid assets to total assets) into the baseline regressions. The coefficients on these liquidity variables are statistically significant but do not materially alter the key relationships. The interaction terms for ProfitBPT × Crisis × Fiscal support and ProfitBPT × Crisis × QE PEPP remain positive and significant, confirming that income smoothing intensified in response to larger fiscal and monetary interventions, consistent with H1 and H2. Thus, our core result – that public support magnified income-smoothing incentives during the pandemic – holds even after accounting for banks' individual liquidity positions.

Next, we decompose fiscal support into its equity injections, loans, and guarantee programs (columns 3–4), and we replace the country-level QE variable with the national share in total PEPP purchases (column 5). The results remain robust: both equity- and guarantee-based fiscal measures are associated with stronger income smoothing and lower LLP levels, reaffirming H1 and H3. Likewise, the alternative PEPP measure yields similar positive interaction effects on income smoothing and negative effects on provisioning, supporting H2.

Overall, the robustness checks confirm that our findings are not driven by liquidity heterogeneity or measurement choice. Across specifications, higher fiscal and monetary support continues to amplify the income-smoothing response while reducing overall provisioning levels. These patterns reinforce both the **crisis-severity channel** where larger policy interventions reflect deeper economic distress – and the **moral-hazard channel**, through which policy backstops expand managerial discretion in LLP-based earnings management.

Table 3. Robustness check of the effect of pandemic severity on income-smoothing

	Governments' fiscal support level (as s % of GDP)	The ECB Pandemic Emergency Purchase Program (as a % of government debt purchased)	Fiscal support: Equity injections and loans	Fiscal support – guarantees	Country level PEPP to total PEPP
Variables	**1**	**2**	**3**	**4**	**5**
			$LLP_{(t-1)}$		
ProfitBPT	0.210***	0.212***	0.196***	0.194***	0.194***
	(0.022)	(0.023)	(0.023)	(0.023)	(0.023)
ProfitBPT × Crisis × Fiscal support	**0.004****		**0.032***	**0.005****	
	(0.002)		**(0.016)**	**(0.002)**	
ProfitBPT × Crisis × QE PEPP		**0.009**			**0.007****
		(0.006)			**(0.003)**
Fiscal support	−0.005***		−0.027**	−0.007***	
	(0.001)		(0.013)	(0.002)	
QE PEPP		−0.016***			−0.005***
		(0.005)			(0.002)
$Liquidity\ ratio_{(t-1)}$	−0.299***	−0.295***			
	(0.093)	(0.093)			
$LtD_{(t-1)}$	−0.002	−0.002			
	(0.002)	(0.002)			
Control variables	yes	yes	yes	yes	yes
Estimator	RE	RE	RE	RE	RE
#Observations	6167	6167	6835	6835	6835
#Banks	1044	1044	1122	1122	1122

Notes: This table displays the test of hypotheses H1 to H3. *LLP* – loan loss provisions scaled by total assets from year *t* – 1. *ProfitBPT*– denotes income before taxes and loan loss provision scaled by total assets from year *t* – 1. *Fiscal support* – denotes government liquidity support to non-financial corporations and enterprises (in % of GDP); *QE PEPP* denotes the net levels of Pandemic Emergence Purchase Program delivered by ECB quantitative easing (in % of total government debt). *ProfitBPT × Crisis × Fiscal support* - denotes the effects of Fiscal Support on income smoothing during the COVID-19 crisis period. *ProfitBPT × Crisis× QE PEPP* – denotes the effects of *QE PEPP* on income smoothing in the COVID-19 crisis period. *Liquidity ratio* is a ratio of liquid assets over liabilities. *LtD* is a loans to deposits ratio. Control variables are the same as in Table 2. Robust standard errors are included in brackets. The coefficients are estimated with a random effects estimator or a dynamic 2-step system GMM. *, **, *** denote significance levels of 10%, 5%, and 1%, respectively.

Source: authors' analysis.

Conclusions

This study investigates income smoothing through loan-loss provisions (LLPs) among commercial banks in the European Economic Area (EEA) during the COVID-19 crisis, focusing on the role of public fiscal and monetary interventions. Using fiscal liquidity measures and the European Central Bank's Pandemic Emergency Purchase Programme (PEPP) as proxies for policy responses, we find that both types of intervention significantly shaped banks' provisioning behavior.

The results indicate that income smoothing intensified in countries with larger fiscal and monetary support, while overall LLP levels declined. These findings suggest a dual mechanism. First, consistent with the crisis-severity channel, greater public spending reflected deeper economic stress and stronger incentives for banks to stabilize earnings amid elevated credit risk. Second, through the moral-hazard channel, extensive policy backstops particularly QE liquidity may have relaxed market discipline and increased managerial discretion in provisioning decisions.

Overall, the evidence supports the **COVID-crisis smoothing hypothesis**: fiscal and monetary interventions mitigated credit losses but simultaneously encouraged greater use of LLPs for earnings management. These results highlight an important policy trade-off. While large-scale stabilization measures helped preserve financial stability, they may have reduced prudential transparency by masking true credit risk. Future research should explore whether similar behavioral patterns persist once policy support is withdrawn and assess the implications for supervisory oversight under prolonged macro-financial intervention regimes.

Funding: We gratefully acknowledge the financial support provided by the National Science Centre (NCN) in Poland, decision No. 2019/35/B/HS4/02471.

References

Allini, A., Prisco, M., Ziebart, D.A., Macchioni, R. (2025), *Earnings management by banks through loan loss provisioning during downturns*, "Journal of Accounting and Public Policy", 50, 107282, https://doi.org/10.1016/j.jaccpubpol.2025.107282

Augeraud-Véron, E., Boungou, W., Gupta, P. (2025), *Do better capitalized and bigger banks recover faster from a pandemic-led shock? Evidence from U.S. Banks' lending behavior*, "Economic Modelling", 151, 107179, https://doi.org/10.1016/j.econmod.2025.107179

Baltagi, B.H. (2005), *Econometric Analysis of Panel Data*, John Wiley and Sons Ltd., Chichester.

Beatty, A.L., Ke, B., Petroni, K.R. (2002), *Earnings Management to Avoid Earnings Declines across Publicly and Privately Held Banks*, "Accounting Review", 77 (3), pp. 547–570, https://doi.org/10.2308/accr.2002.77.3.547

Bell, A., Fairbrother, M., Jones, K. (2018), *Fixed and random effects models: Making an informed choice*, "Quality & Quantity", 53, pp. 1051–1074, https://doi.org/10.1007/s11135-018-0802-x

Bell, A., Jones, K. (2015), *Explaining Fixed Effects: Random Effects Modeling of Time-Series Cross-Sectional and Panel Data*, "Political Science Research and Methods", 3 (1), pp. 133–153, https://doi.org/10.1017/psrm.2014.7

Berger, A.N., Demirgüç-Kunt, A. (2021), *Banking research in the time of COVID-19*, "Journal of Financial Stability", 57, 100939, https://doi.org/10.1016/j.jfs.2021.100939

Bouvatier, V., Lepetit, L., Strobel, F. (2014), *Bank income smoothing, ownership concentration and the regulatory environment*, "Journal of Banking and Finance", 41, pp. 253–270, https://doi.org/10.1016/j.jbankfin.2013.12.001

Curcio, D., De Simone, A., Gallo, A. (2017), *Financial crisis and international supervision: New evidence on the discretionary use of loan loss provisions at Euro Area commercial banks*, "British Accounting Review", 49 (2), pp. 181–193, https://doi.org/10.1016/j.bar.2016.09.001

Degryse, H., Huylebroek, C. (2023), *Fiscal support and banks' loan loss provisions during the COVID-19 crisis*, "Journal of Financial Stability", 67, 101150, https://doi.org/10.1016/j.jfs.2023.101150

Demir, E., Danisman, G.O. (2021), *Banking sector reactions to COVID-19: The role of bank-specific factors and government policy responses*, "Research in International Business and Finance", 58, 101508, https://doi.org/10.1016/j.ribaf.2021.101508

Demirgüç-Kunt, A., Horváth, B.L., Huizinga, H. (2023), *Corporate QE in Europe during the COVID-19 crisis and debt overhang*, "Journal of International Money and Finance", 135, 102855, https://doi.org/10.1016/j.jimonfin.2023.102855

Demirgüç-Kunt, A., Pedraza, A., Ruiz-Ortega, C. (2021), *Banking sector performance during the COVID-19 crisis*, "Journal of Banking and Finance", 133, 106305, https://doi.org/10.1016/j.jbankfin.2021.106305

Di Fabio, C., Ramassa, P., Quagli, A. (2021), *Income smoothing in European banks: The contrasting effects of monitoring mechanisms*, "Journal of International Accounting, Auditing and Taxation", 43, 100385, https://doi.org/10.1016/j.intaccaudtax.2021.100385

Duan, Y., El Ghoul, S., Guedhami, O., Li, H., Li, X. (2021), *Bank systemic risk around COVID-19: A cross-country analysis*, "Journal of Banking and Finance", 133, 106299, https://doi.org/10.1016/j.jbankfin.2021.106299

El Sood, H.A. (2012), *Loan loss provisioning and income smoothing in US banks pre and post the financial crisis*, "International Review of Financial Analysis", 25, pp. 64–72, https://doi.org/10.1016/j.irfa.2012.06.007

Elnahass, M., Trinh, V.Q., Li, T. (2021), *Global banking stability in the shadow of Covid-19 outbreak*, "Journal of International Financial Markets, Institutions and Money", 72, 101322, https://doi.org/10.1016/j.intfin.2021.101322

European Central Bank (2020), *ECB announces €750 billion Pandemic Emergency Purchase Programme (PEPP)*, https://www.ecb.europa.eu/press/pr/date/2020/html/ecb.pr200318_1~3949d6f266.en.html (accessed: 23.01.2026).

Fan, Y., Jiang, Y., Zhang, X., Zhou, Y. (2019), *Women on boards and bank earnings management: From zero to hero*, "Journal of Banking and Finance", 107, 105607, https://doi.org/10.1016/j.jbankfin.2019.105607

Fonseca, A., González, F. (2008), *Cross-country determinants of bank income smoothing by managing loan-loss provisions*, "Journal of Banking and Finance", 32 (2), pp. 217–228, https://doi.org/10.1016/j.jbankfin.2007.02.012

Gebhardt, G., Novotny-Farkas, Z. (2011), *Mandatory IFRS Adoption and Accounting Quality of European Banks*, "Journal of Business Finance and Accounting", 38 (3–4), pp. 289–333, https://doi.org/10.1111/j.1468-5957.2011.02242.x

Hansen, S., Charifzadeh, M., Herberger, T.A. (2024), *The impact of IFRS 9 on the cyclicality of loan loss provisions*, "Journal of Corporate Accounting & Finance", 35 (2), pp. 37–49, https://doi.org/10.1002/jcaf.22669

IMF (2021), *IMF Fiscal Monitor: Database of Country Fiscal Measures in Response to the COVID-19 CRISIS Pandemic*, https://www.imf.org/en/topics/imf-and-covid19/fiscal-policies-database-in-response-to-covid-19 (accessed: 21.01.2026).

Kim, J., Kim, M., Lee, J.H. (2019), *The effect of TARP on loan loss provisions and bank transparency*, "Journal of Banking and Finance", 102, pp. 79–99, https://doi.org/10.1016/j.jbankfin.2019.03.006

Ma, Y., Lan, H. (2025), *How does monetary policy shock affect banks' loan loss provisioning behavior? Evidence from Chinese commercial banks*, "China Economic Review", 91, 102395, https://doi.org/10.1016/j.chieco.2025.102395

Mundlak, Y. (1978), *Pooling of time-series and cross-section data*, "Econometrica", 46 (1), pp. 69–85.

Nguyen, T.A., Nguyen, P.H., Luu, H.N., Cu, T.N.H., Nguyen, P.A. (2023), *Bank provisioning practice during the pandemic: evidence from the COVID-19 outbreak*, "International Journal of Disclosure and Governance", 20 (3), pp. 248–260, https://doi.org/10.1057/s41310-022-00169-x

Niermann, L., Pitterle, I.A. (2021), *The COVID-19 Crisis: What Explains Cross-country Differences in the Pandemic's Short-term Economic Impact?*, "United Nations DESA Working Paper", 174, https://www.un-ilibrary.org/content/papers/10.18356/25206656-174 (accessed: 21.01.2026).

Olszak, M., Godlewski, C.J., Roszkowska, S., Skała, D. (2025), *Loan loss provisions of European banks – Does macroprudential tightening matter?*, "Research in International Business and Finance", 73 (B), 102642, https://doi.org/10.1016/j.ribaf.2024.102642

Ozili, P.K., Thankom, A.G. (2018), *Income smoothing among European systemic and non-systemic banks*, "British Accounting Review", 50 (5), pp. 539–558, https://doi.org/10.1016/j.bar.2018.03.001

Pinto, I., Ng Picoto, W. (2018), *Earnings and capital management in European banks – Combining a multivariate regression with a qualitative comparative analysis*, "Journal of Business Research", 89, pp. 258–264, https://doi.org/10.1016/j.jbusres.2017.12.034

Silva, T.C., Souza, S.R.S. de, Guerra, S.M., Tabak, B.M. (2023), *COVID-19 and bank branch lending: The moderating effect of digitalization*, "Journal of Banking and Finance", 152, 106869, https://doi.org/10.1016/j.jbankfin.2023.106869

Simper, R., Dadoukis, A., Bryce, C. (2019), *European bank loan loss provisioning and technological innovative progress*, "International Review of Financial Analysis", 63, pp. 119–130, https://doi.org/10.1016/j.irfa.2019.03.001

Skała, D. (2020), *Shareholder shocks and loan loss provisions in Central European banks*, "Journal of International Financial Markets, Institutions and Money", 69, 101244, https://doi.org/10.1016/j.intfin.2020.101244

Skała, D. (2021), *Loan loss provisions and income smoothing – Do shareholders matter?*, "International Review of Financial Analysis", 78, 101909, https://doi.org/10.1016/j.irfa.2021.101909

Wieland, V. (2022), *Overview of how major economies have responded to the Covid-19 pandemic. Growth trajectories, debt sustainability, best practices*, ECON Committee, https://www.europarl.europa.eu/RegData/etudes/STUD/2022/689450/IPOL_STU(2022)689450_EN.pdf (accessed: 21.01.2026).

Wsparcie fiskalne, luzowanie ilościowe (QE) i wygładzanie dochodów w europejskich bankach podczas kryzysu związanego z COVID-19

W badaniu podjęto próbę określenia, w jaki sposób reakcje polityki fiskalnej i monetarnej na kryzys związany z pandemią COVID-19 wpłynęły na wygładzanie dochodów przez banki w krajach Europejskiego Obszaru Gospodarczego (EOG). Wykorzystując dane panelowe obejmujące 1122 banki komercyjne z 29 krajów w latach 2011–2020, autorzy badają, czy intensywność wygładzania dochodów różniła się w zależności od skali wsparcia publicznego. Miary wsparcia fiskalnego w zakresie płynności oraz luzowanie ilościowe (QE) Europejskiego Banku Centralnego w ramach Pandemic Emergency Purchase Programme (PEPP) służą jako miara skali interwencji rządowych i monetarnych. Wyniki wskazują, że zarówno wsparcie fiskalne, jak i monetarne obniżyło przeciętny poziom rezerw na ryzyko kredytowe (LLP), ale jednocześnie wzmocniło zależność między dochodami operacyjnymi a wielkością tworzonych LLP, co sugeruje nasilenie zjawiska wygładzania dochodów w czasie pandemii. Wzorzec ten odzwierciedla dwa uzupełniające się mechanizmy: kanał dotkliwości kryzysu, w którym większe interwencje polityczne odpowiadały głębszym zaburzeniom gospodarczym, oraz kanał pokusy nadużycia, w którym publiczne zabezpieczenia zwiększały swobodę menedżerów w kształtowaniu rezerw. Wyniki sugerują, że szeroko zakrojone działania stabilizacyjne ograniczyły ryzyko kredytowe i przyczyniły się do utrzymania stabilności finansowej, ale jednocześnie sprzyjały bardziej uznaniowym praktykom rachunkowym, co wskazuje na potencjalne napięcie między skutecznym zarządzaniem kryzysem a przejrzystością raportowania finansowego banków.

Słowa kluczowe: rezerwy na straty kredytowe, wygładzanie dochodów, wsparcie płynności

Comparative Economic Research. Central and Eastern Europe
Volume 29 Number 1, 2026
https://doi.org/10.18778/1508-2008.29.06

How Financial Inclusion Affects Environmental Pollution: Using a Threshold and the DID Model

Yen Nguyen https://orcid.org/0009-0002-0254-2236
Ph.D., Lecturer, Faculty of Finance, Ho Chi Minh University of Banking, Ho Chi Minh City, Vietnam,
e-mail: yenndh@hub.edu.vn

Abstract

This study investigates the nonlinear impact of financial inclusion on environmental pollution across 61 developing countries from 2005 to 2022. Using a threshold regression model, the findings reveal a critical threshold at which the impact of financial inclusion changes direction. Below this threshold, financial inclusion tends to increase carbon emissions; however, beyond this point, the relationship reverses, with financial inclusion contributing to pollution reduction. To gain deeper insights, the study further applies the Difference-in-Differences (DID) method. The DID results indicate that the effect of financial inclusion is heterogeneous and depends on the level of financial development, national income, and the timing of each country's participation in the Paris Agreement on climate change. These findings underscore the multidimensional nature of the relationship between financial inclusion and the environment, which is significantly influenced by country-specific economic and policy factors. In addition, the study finds that national income and urbanization levels are associated with increased pollution, while credit to the private sector plays a mitigating role in reducing emissions. These results have important implications that policymakers should consider when designing strategies that promote financial inclusion while aligning with Sustainable Development Goals.

Keywords: financial inclusion, environmental pollution, DID method, Panel Threshold Regression
JEL: F4, G2, Q4, Q54, Q56

Funding information: Faculty of Finance, Ho Chi Minh University of Banking, Ho Chi Minh City, Vietnam.
Declaration regarding the use of GAI tools: Not used.
Conflicts of interests: None.
Ethical considerations: The Author assures of no violations of publication ethics and takes full responsibility for the content of the publication.
Received: 7.10.2025. Verified: 3.11.2025. Accepted: 30.01.2026

Introduction

In recent decades, global economic growth and technological progress have brought prosperity but also intensified environmental degradation, especially in developing countries. Rapid industrialization, urban expansion, and increasing energy consumption have led to severe carbon emissions and environmental pollution, threatening sustainable development goals (Baloch and Wang 2019). These challenges raise a critical question for policymakers: How can countries simultaneously expand financial access, foster economic growth, and protect the environment?

Financial inclusion the process of ensuring access to useful and affordable financial services for individuals and businesses has emerged as an important driver of inclusive growth and social equity (Chibba 2009). However, its environmental implications remain ambiguous. On the one hand, improved financial inclusion may facilitate investment in clean technologies, energy efficiency, and green innovation (Le, Le, and Taghizadeh-Hesary 2020). On the other hand, easier access to credit and capital can accelerate industrial activity and household consumption, increasing energy use and pollution (Qin et al. 2021). Therefore, theoretically, the impact of financial inclusion on environmental pollution can be either beneficial or harmful, depending on a country's stage of development, financial depth, and environmental regulations

Despite growing research interest, existing studies reveal several limitations. First, most prior works have analyzed the relationship between financial inclusion and environmental pollution using linear models (Rehman, Fareed, and Shahzad 2022; Hussain et al. 2024), overlooking potential nonlinear or threshold effects. However, the Environmental Kuznets Curve (EKC) hypothesis suggests that the relationship between growth-related variables and environmental quality often follows a nonlinear pattern with negative effects at low development levels that reverse beyond a certain threshold (Tan, Lean, and Khan 2014; Ali et al. 2021). Second, while some recent studies identify a U-shaped or inverted-U relationship (Renzhi and Baek 2020; Amin, Song, and Khan 2022), they have not formally tested the existence of a specific threshold value of financial inclusion at which its impact on pollution changes direction. Third, prior research rarely considers the heterogeneous impacts across countries, such as differences in income levels or participation in international environmental agreements, which may moderate the relationship between financial inclusion and environmental outcomes.

To address these gaps, this study examines how financial inclusion affects environmental pollution in developing countries, focusing on both nonlinear (threshold) effects and heterogeneous effects using a Difference-in-Differences (DID) approach. Specifically, this study addresses the following research questions:

Does financial inclusion have a nonlinear (threshold) effect on environmental pollution in developing countries?

1. How does national income moderate the relationship between financial inclusion and environmental pollution?
2. How does participation in the Paris Agreement influence the environmental impact of financial inclusion?

To answer these questions, the study develops a theoretical model based on financial circulation and financial stability theories, combined with the EKC framework. The analysis uses panel data from 61 developing countries covering 2005–2022. The panel threshold regression (PTR) method is applied to identify the critical value of financial inclusion beyond which its environmental effect changes sign, while the DID model is employed to explore heterogeneity across income groups and Paris Agreement participation.

This research contributes to the literature in three main ways. First, it extends the environmental finance literature by revealing the threshold level of financial inclusion at which its impact on pollution shifts from harmful to beneficial. Second, it integrates the DID approach to reveal how country-specific characteristics economic development and environmental commitments shape this relationship. Finally, it discusses the policy implications for achieving inclusive and sustainable finance by aligning financial inclusion strategies with environmental objectives.

The rest of the paper is organized as follows. Section 2 reviews the theoretical framework and empirical evidence. Section 3 presents the data and methodology. Section 4 discusses the empirical results, and Section 5 concludes with policy implications.

Literature review

Theoretical Framework for Financial Inclusion

Financial inclusion plays a crucial role in promoting financial development and inclusive economic growth (Sarma and Pais 2008). It is grounded in financial intermediation theory, which emphasize that expanding access to financial services fosters savings, encourages productive investment, and improves economic resilience.

Financial inclusion is a multidimensional concept that broadly reflects the extent to which individuals and businesses have access to, and make effective use of, formal financial services. In this study, financial inclusion is primarily represented by two measurable dimensions, access and usage, which correspond to the availability and actual utilization of financial resources such as credit, savings, and banking infrastructure (Sarma 2016).

The access dimension determines the extent to which people and firms can obtain financial services and external financing. Expanded access to credit and savings mobilization may initially stimulate industrial activities and energy consumption, but it can also support investment

in cleaner production and renewable technologies when directed through sustainable channels. The usage dimension, on the other hand, reflects how financial services are employed. Greater utilization of financial instruments can enhance investment efficiency, encourage the adoption of green technologies, and promote environmentally responsible business practices.

Beyond these measurable aspects, the quality dimension though not captured in this study's empirical indicators – represents a crucial complementary channel. It includes factors such as financial literacy (knowledge), the technological capacity of financial institutions, and the efficiency of financial regulation, all of which determine how effectively inclusive finance contributes to sustainable outcomes.

Accordingly, this framework recognizes that financial inclusion and economic development are mutually reinforcing. Economic growth facilitates financial participation, while inclusive finance acts as a transmission mechanism that influences whether such growth follows a carbon-intensive trajectory or a sustainable, low-carbon pathway.

It is important to recognize that the relationship between financial inclusion and economic development is inherently bidirectional (Sarma and Pais 2011). While economic and financial progress expands access to financial services by improving education, income, and infrastructure, financial inclusion, in turn, plays a transmission role that shapes how development affects environmental outcomes. Through broader access to credit, savings, and financial technologies, inclusive finance mobilizes resources for productive investment and influences the allocation of capital across sectors. Consequently, financial inclusion determines whether economic growth evolves along a carbon-intensive path or transitions toward green and sustainable development. This reciprocal dynamic justifies the examination of financial inclusion not as an isolated determinant, but as a mediating mechanism linking financial and environmental systems.

According to the financial intermediation theory, financial inclusion promotes economic growth by enhancing the efficiency of financial markets and reducing frictions between savers and borrowers. Financial inclusion supports economic development through three main channels: (1) the direct channel, where individuals previously excluded from formal finance gain access to credit and savings tools; (2) the indirect channel, where small and medium enterprises can invest, create jobs, and stimulate economic activity; and (3) the market channel, where broader financial participation increases liquidity and improves market efficiency.

The principles of financial stability posit that a more inclusive financial system strengthens the overall stability of the economy by diversifying risk and expanding the financial base. When linked with the EKC hypothesis, financial inclusion may exhibit a nonlinear relationship with environmental quality. At early stages, increased financial access may raise emissions due to industrialization, but beyond a certain level, it can facilitate green finance, technological innovation, and investments in renewable energy – ultimately reducing pollution (Tan, Lean, and Khan 2014; Ali et al. 2021).

The Impact of Financial Inclusion on Environmental Pollution

Existing studies exploring the nexus between financial inclusion and environmental pollution reveal diverse and sometimes contradictory findings.

The first group of studies supports the "pollution haven" hypothesis, suggesting that expanding financial inclusion increases environmental degradation. Wider access to financial services can stimulate consumer demand and enable industrial expansion, leading to higher energy consumption and emissions (Tamazian, Chousa, and Vadlamannati 2009; Renzhi and Baek 2020; Liu, Hong, and Sohail 2022; Wang et al. 2022). Studies in BRICS[1] countries and the Organisation for Economic Co-operation and Development (OECD) countries have also found that financial inclusion tends to increase carbon emissions due to intensified production activities and relaxed environmental regulations (Zaidi, Hussain, and Zaman 2021; Dou and Li 2022).

In contrast, other research demonstrates a "halo effect", where financial inclusion supports environmental improvement. Greater access to credit and digital finance encourages investment in renewable energy, promotes environmental awareness, and allows firms to adopt cleaner production technologies (Gill, Hassan, and Haseeb 2019; Du et al. 2022). Chaudhry, Yusop, and Habibullah (2022) also confirmed this effect in Organisation of Islamic Cooperation (OIC) countries, emphasizing that financial inclusion facilitates structural transformation toward green and efficient industries.

Some recent studies uncover nonlinear dynamics. Le, Le, and Taghizadeh-Hesary (2020) found that, in Asia, financial inclusion initially worsens CO_2 emissions but later contributes to reduction when combined with green policies. Similarly, Amin, Song, and Khan (2022) reported short-term mitigation but long-term deterioration effects in South Asia. Qin et al. (2021) used quantile regressions and found that the effect varies across emission levels and stages of financial development. However, few studies have explicitly tested for a threshold level of financial inclusion beyond which its environmental impact reverses.

Hence, the literature reveals mixed evidence, highlighting the need to explore whether a critical threshold exists, and to what extent country-specific characteristics such as income levels and climate policy participation alter this relationship. Therefore, the environmental impact of financial inclusion depends not only on its overall expansion but also on the composition of its components. When financial access primarily supports credit for energy-intensive sectors, environmental degradation tends to increase.

It should be noted that greater access to credit does not automatically translate into environmental improvement. The environmental effect of credit depends largely on how and where these financial resources are allocated. When credit is mainly directed toward energy-intensive or resource-consuming industries, it may aggravate environmental degradation. In contrast, when credit supports pro-ecological or green investments such as renewable energy, clean technologies, and energy-efficient infrastructure it can significantly contribute to environmental

1 The BRICS countries initially comprised Brazil, Russia, India, and China. Today, it includes an additional six countries: Egypt, Ethiopia, Indonesia, Iran, South Africa, and the United Arab Emirates.

sustainability. Therefore, the relationship between financial inclusion and environmental pollution is nonlinear and context-dependent, operating through indirect and conditional channels, determined by the policy framework, the structure of financial markets, and the environmental orientation of financial institutions.

Moderating Factors: National Income and Environmental Commitments

The interaction between financial inclusion and environmental quality is shaped by macroeconomic and institutional contexts.

Higher-income countries typically have greater technological capacity and regulatory enforcement, enabling financial inclusion to support investments in cleaner production. In contrast, lower-income economies may rely on carbon-intensive growth paths, were expanding finance fuels further emissions.

Participation in international environmental agreements, particularly the Paris Agreement, can also moderate this relationship. Countries with stronger commitments tend to redirect financial inclusion toward green projects and renewable energy initiatives. By contrast, nations that joined the Paris Agreement later or enforce weaker environmental regulations may not realize similar benefits.

Therefore, understanding how income heterogeneity and environmental governance influence the financial inclusion–pollution nexus is essential for designing effective, context-specific sustainable finance policies.

Research Hypotheses

Based on the theoretical framework and the reviewed literature, the relationship between financial inclusion and environmental pollution is expected to be nonlinear, and its magnitude may differ depending on income levels and environmental policy commitments.

First, the EKC hypothesis implies that the effect of financial inclusion on pollution can vary at different stages of financial and economic development. At lower levels, expanding financial inclusion might intensify energy demand and industrial activities, thereby increasing emissions. However, beyond a certain threshold, it may promote green investments, energy efficiency, and cleaner production. This reasoning leads to the first hypothesis:

H_1: There is a nonlinear (threshold) effect of financial inclusion on environmental pollution in developing countries.

Second, the level of economic development determines how effectively financial inclusion can support green initiatives. Higher-income countries often have better institutional quality, environmental regulations, and technological infrastructure that channel financial inclusion toward sustainable activities. In contrast, in low-income economies, expanding credit access might exacerbate emissions due to industrial expansion without adequate green oversight. Therefore:

H_2: The impact of financial inclusion on environmental pollution is moderated by national income; financial inclusion reduces pollution more effectively in higher-income countries.

Third, international environmental commitments such as the Paris Agreement can strengthen the environmental benefits of financial inclusion. Countries that joined the Agreement earlier or enforce stricter environmental policies are more likely to use inclusive finance as a tool for green transformation. Hence, we propose:

H_3: The effect of financial inclusion on environmental pollution is influenced by participation in the Paris Agreement; countries committed to the Agreement experience a stronger pollution-reducing effect of financial inclusion.

These hypotheses will be tested using a combination of Panel Threshold Regression (PTR) and Difference-in-Differences (DID) methods, allowing the study to capture both nonlinear effects and cross-country heterogeneity.

Research method

Model

Based on the EKC hypothesis, the study constructs a research model with the dependent variable being CO_2 emissions as a function of the following form:

$$CO_2 = f(IFI,\ GDP,\ URB,\ DCP), \tag{1}$$

where CO_2 is carbon dioxide emissions, IFI represents the financial inclusion variable, GDP is Gross Domestic Product, URB is the urbanization process, and DCP is credit to the private sector.

The indicators used to construct the financial inclusion – the number of bank branches and ATMs per 100,000 adults, the ratio of deposits to GDP, and the ratio of private credit to GDP – were taken from the IMF Financial Access Survey. These indicators are widely used in cross-country studies (Sarma 2008; Ahamed and Mallick 2019) due to their long-term availability and comparability.

Although digital financial services have become increasingly important, comparable cross-country data for digital and account-based indicators remain limited, particularly for developing countries in the early 2000s. Therefore, consistent with prior studies and IMF Financial Access Survey standards, this study employs the number of commercial bank branches and ATMs per 100,000 adults as conventional proxies for financial inclusion. These indicators capture the accessibility of formal financial services in a way that remains relevant for many developing economies.

According to the EKC hypothesis, economic development plays a crucial role in impacting the environment. Therefore, the GDP variable is included in the research model. Previous studies acknowledge that urbanization demands a significant amount of natural resources to produce goods for domestic consumption (Charfeddine and Mrabet 2017). Urbanization also brings about

several changes to the economic development process, such as the expansion of infrastructure and the development of diversified businesses across multiple sectors, thereby affecting the environment. Finally, DCP is included in the study because credit to this sector is substantial, providing businesses with opportunities to innovate, invest in machinery and equipment, and improve technology, consequently impacting environmental pollution (Frankel and Romer 2017).

To test Hypothesis H_1, based on Renzhi and Baek (2020), we employ the PTR model for panel data. The research model is structured as follows:

$$CO_{2it}\begin{cases}\mu_i + \beta^{'}X_{it} + \alpha_1 IFI_{it} + \varepsilon_{it} IFI_{it} \leq \gamma \\ \mu_i + \beta^{'}X_{it} + \alpha_2 IFI_{it} + \varepsilon_{it} IFI_{it} > \gamma\end{cases} \quad (2)$$

Wherein, vector $\beta^{'} = (\beta_1, \beta_2, \beta_3)$ is the regression coefficient of independent variables that do not change across thresholds. X_{it} is the vector of explanatory variables that impact environmental pollution, including URB_{it}, DCP_{it}, and GDP_{it}. γ is the threshold value at which the relationship between financial inclusion and environmental pollution changes. IFI is financial inclusion, which is determined by the Principal Component Analysis (PCA) method from four indicators: the ratio of bank branches per 100,000 adults, the ratio of ATMs per 100,000 adults, the ratio of deposits to GDP, and the ratio of private credit to GDP. These indicators have been widely used in previous studies (Sarma 2008; 2016; Gupte, Venkataramani, and Gupta 2012; Ahamed and Mallick 2019). α_1, α_2 are, respectively, the regression coefficients of IFI when IFI is less than or equal to γ and greater than the threshold value γ, μ_i is the constant term, while ε_{it} is the error term of the model, which has an independent and identically distributed random distribution with an expected value of 0 and constant variance.

After determining the appropriate model and collecting research data, we perform descriptive statistics to identify the characteristics of the research data and remove outliers. Subsequently, the study analyzes the correlation matrix to examine the correlation between variables in the model. Due to the data's time dimension spanning 18 years, stationarity testing is necessary. Before conducting stationarity tests, if cross-sectional dependence exists in the research data, second-generation stationarity tests are required; otherwise, first-generation stationarity test methods are applied. If stationarity testing is appropriate, the author proceeds to conduct the F1 statistic test to examine whether there exists a threshold effect of financial inclusion on environmental pollution (Hansen 2000), with the following hypothesis:

$$H_0 : \alpha_1 = \alpha_2 : Nothresholdexists.$$

$$H_1 : \alpha_1 \neq \alpha_2 : Athresholdexists.$$

Hansen's method employs the bootstrap technique to simulate an approximate distribution of the standard normal distribution with the LR statistic. If the p-value is statistically significant, it indicates the existence of a threshold effect of financial inclusion on environmental pollution. If the test results show the existence of a threshold effect, the author proceeds to perform PTR model regression to determine how the impact coefficients change in each threshold regime.

To test Hypotheses H_2 and H_3, we employ the DID approach. The DID model compares changes in environmental pollution between a treated group and a control group before and after a temporal break. In this study, the treatment assignment is based solely on financial inclusion. Specifically, Post is a time dummy equal to 1 in the post-policy period and 0 otherwise, while Treat equals 1 for countries whose financial inclusion index is above the sample mean and 0 for the rest. The interaction term DID = Post × Treat captures the differential change in CO_2 emissions for high-FI countries relative to low-FI countries following the policy shock.

$$CO_{2it} = \beta_0 + \beta_1 post_{it} + \beta_2 treat_{it} + \beta_3 post_{it} \times \quad treat_{it} + \varepsilon_{it}. \tag{3}$$

Hypothesis H_2 examines whether the effect of financial inclusion differs across income levels. For this purpose, income is included strictly as a moderating variable and not as part of the treatment assignment. Countries with income levels above the median value are coded as 1 and those below the median as 0. This classification creates a higher-income (above-median) and lower-income (below-median) group within the sample. An extended interaction term is introduced to evaluate whether the DID effect varies across these income groups.

Similarly, Hypothesis H_3 investigates whether participation in the Paris Agreement strengthens the pollution-reducing effect of financial inclusion. A Paris Agreement dummy (1 = signatory; 0 = non-signatory) is also introduced purely as a moderator. It is not used to construct either Post or Treat, but interacts with the DID term to capture policy heterogeneity associated with international climate commitments.

Data research

The study uses data from 61 developing countries over the period 2005 to 2022. The characteristics of the PTR model require balanced data; therefore, to satisfy this condition, the research data is limited to 2022. Data on carbon emissions, urbanization, private sector credit, and economic growth were extracted from the World Bank database, accessed via the website https://databank.worldbank.org/. Data on financial inclusion were collected from the International Monetary Fund's Financial Access Survey database, accessed via the website: https://data.imf.org/. The data in the paper are winsorized at the 99th percentile. Table 1 presents information about the variables in the model.

Table 1. Descriptive variables

Sign	Descriptive	Calculation	Sources
CO_2	Carbon emission		WB
IFI	Financial inclusion	PCA method from four indicators: the ratio of bank branches per 100,000 adults, the ratio of ATMs per 100,000 adults, the ratio of deposits to GDP, and the ratio of private credit to GDP.	IMF
GDP	National income	GDP *per capita*	WB
URB	Urbanization	Ratio of urban population to total population	WB
DCP	Private sector credit	Ratio of private sector credit to GDP	WB

Source: author's elaboration.

Results

Descriptive Statistics

Table 2. Descriptive Statistics

Variables	Obs	Average	Std	Min	Max
CO_2	1098	3.867	4.910	0.086	29.99
IFI	1098	0.465	0.235	0.001	1.216
GDP	1098	8.364	1.012	5.633	10.440
URB	1098	58.396	18.036	14.841	95.603
DCP	1098	55.183	62.082	2.010	525.703

Source: Stata output.

According to the data collected, the average carbon emissions fluctuated around 3.867 tons per person. The highest value was 29.99 tons per person, recorded in Trinidad and Tobago in 2011, while the lowest was found in Madagascar in 2009, reaching 0.086 tons per person. The average value of financial inclusion was 0.465, with the highest value observed in Malta in 2011. The average urbanization rate was 58.39%, the average per capita income was 8,364, and the average value of the urbanization speed index was 55.163%.

Autocorrelation Matrix

Table 3. Autocorrelation Matrix

Variables	CO_2	IFI	GDP	URB	DCP
CO_2	1.000				
IFI	0.3424	1.000			
GDP	0.6219	0.5158	1.000		
URB	0.3430	0.3656	0.5334	1.000	
DCP	0.1390	0.5806	0.2705	0.0691	1.000

Source: Stata output.

The correlation matrix shows that financial inclusion (IFI) is positively correlated with CO_2 emissions (r = 0.3424), implying that greater access to financial services may stimulate economic and consumption activities that increase energy use and carbon output. Compared with other variables, GDP (r = 0.629) and urbanization (r = 0.3430) also exhibit positive links with CO_2 emissions, while domestic credit to the private sector (r = 0.1390) shows a weaker relationship. Overall, the moderate correlation between IFI and CO_2 suggests that financial inclusion might influence environmental quality mainly through economic and energy channels.

Cross-sectional Dependence and Stationarity Tests

Cross-sectional dependence testing of the variables is essential to examine whether there is a relationship between countries. The results of the cross-sectional dependence test, following Pesaran (2004) with the series of variables, are shown in Table 4.

Table 4 indicates that all series reject the null hypothesis at a significant level of 1%. Thus, cross-sectional dependence exists among countries. Therefore, the study employs Pesaran's CADF second-generation stationarity test.

Table 4. Result of Cross-sectional Dependence and Stationarity Tests

Variables	CD Test	P-value	Average ρ	Averageabs (ρ)
CO_2	20.615	0.0000	0.02173	0.9788
IFI	82.272	0.0000	0.0029	0.8299
GDP	129.889	0.0000	0.6201	0.8877
URB	111.099	0.0000	0.0814	0.9779
DCP	55.696	0.0000	0.4580	0.9412

Source: Stata output.

Results regression

Impact of financial inclusion on environmental pollution using the threshold model

Table 5. Regression Results

Threshold Value	5.2500***
(Confidence Interval 95%)	4.9100 – 5.3900
α_1	0.5763**
α_2	– 2.7783**
dGDP	0.0000***
dURB	0.0467***
dDCP	– 0.5899***

Note: *, ** and, *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Stata output.

Table 5 indicates a non-linear relationship between financial inclusion and environmental pollution within Table 5 shows evidence of a non-linear relationship between financial inclusion and environmental pollution in developing countries. This finding is consistent with Renzhi and Baek (2020), who also document threshold effects in the finance–environment nexus.

The estimated threshold value is 5.25, indicating a statistically significant change in the effect of financial inclusion once this point is crossed. Before the threshold, the coefficient of financial inclusion is positive (0.5763), suggesting that at lower levels of financial inclusion, expanding access to finance may unintentionally increase pollution – possibly reflecting early-stage economic

expansion that prioritizes growth over environmental considerations. Above the threshold, the coefficient becomes negative (–2.7783), implying that higher levels of financial inclusion contribute to reducing environmental pollution. This indicates that once a country reaches a sufficiently developed financial inclusion level, financial access begins to facilitate cleaner technologies, improved resource allocation, and environmentally responsible investment.

Our findings simultaneously indicate that the growth rate of gross national income and population urbanization contribute to increasing environmental pollution. It can be observed that economic growth in developing countries relies on heavy industries that require substantial natural resources, which has detrimental effects on the environment. Furthermore, these nations face a trade-off between economic growth and environmental concerns, leading to less stringent processes in treating industrial waste. Moreover, during the development phase, rising incomes often drive increased consumption of durable goods, further contributing to pollution; such a finding was also reported by Baloch et al. (2021). Concurrently, urbanization, which leads to higher concentrations of populations in urban areas, compels leaders to develop infrastructure. The research findings align with Alola, Bekun, and Sarkodie (2019).

Conversely, the variable of credit to the private sector has a mitigating impact on environmental pollution. In many developing countries, the private sector is largely composed of small-scale enterprises that lack experience and credibility, with limited business capacity, making it very difficult to invest in modern, clean technology. Therefore, when credit to the private sector increases, bank loans enable these private enterprises to upgrade equipment, enhance product quality, and maintain and expand markets. This crucial factor helps these enterprises improve their production and business processes, thereby potentially reducing CO_2 emissions.

Furthermore, the LR Statistics value is greater than 8.37 (Figure 1), which is statistically significant, demonstrating that the regression model is appropriate.

The study further investigates whether there are two impact thresholds of financial inclusion on environmental pollution. The bootstrap results show that the p-value at the second threshold is 0.2750, indicating that there is no single impact threshold of financial inclusion on environmental pollution.

Thus, the results provide empirical evidence for the hypothesis regarding the non-linear relationship between financial inclusion and environmental pollution. To test the robustness of these findings, we employ the Ordinary Least Squares (OLS) regression method with the original baseline model and include the squared term of financial inclusion. If the regression coefficient of IFI exhibits a negative value, it signifies the existence of a non-linear relationship. The results are presented in Table 6.

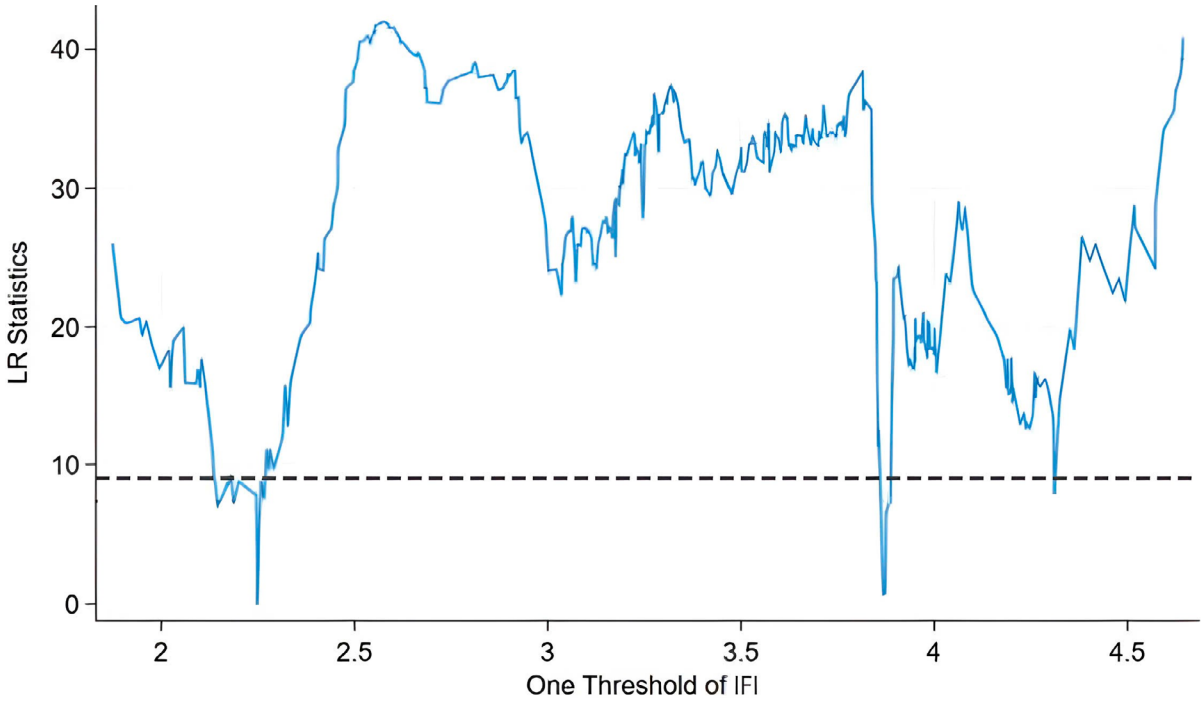


Figure 1. One-threshold test of IFI
Source: Stata output.

Table 6. Non-linear Effect Test Results

Variables	
IFI	3.238*
IFI^2	−1.707*
GDP	0.000***
URB	0.000
DCP	−0.004***
cons	−0.187*
R^2	0.5888

Note: *, ** and, *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.
Source: Stata output.

Impact of Income

In this section, we utilize the DID method to assess how the impact of financial inclusion on environmental pollution differs between countries grouped by *per capita* income and financial inclusion level. Table 7 presents the parameters in the DID model, and Table 9 presents the results.

Table 7. Descriptive Statistics of Data in the DID Method

Time variable	Year	Control (Treat = 0)	Treatment (Treat = 1)
Firm		611	505

Source: Stata output

The results in Table 8 indicate a balanced distribution of the sample, with 611 observations in the control group (Treat = 0) and 505 observations in the treatment group (Treat = 1). The clear identification of control and treatment groups based on the treatment variable is essential for evaluating the causal effect within the DID framework. Overall, the sample sizes in both groups are adequate to support reliable conclusions regarding the impact of financial inclusion on environmental pollution.

The results in Table 8 show that the DID coefficient is negative and statistically significant at the 10% level. This suggests that the reduction in environmental pollution is significantly stronger for higher-income countries with higher levels of financial inclusion compared to the lower-income countries.

Table 8. DID Method Results

	Coefficient	S. Err.	t	P > |t|
DID	−0.405	0.226	1.79	0.073***

Note: *, ** and, *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Stata output.

Based on the analysis results obtained using the DID method, this study accepts hypothesis H_2, affirming that the income level of countries has a significant influence on the impact of financial inclusion on the environment. The finding suggests that variations in income across different countries may lead to changes in the relationship between financial inclusion and environmental pollution. Consequently, the effectiveness of promoting financial inclusion for environmental protection may not be uniform across countries, but depends heavily on economic characteristics, as represented by the income level of each nation.

Impact of Paris Agreements

As with the examination of how income levels affect the impact of financial inclusion on environmental pollution, we concurrently examine the effects of two factors: participation in the Paris Agreement and the level of financial inclusion, using the DID method. The results are presented in Table 9 and Table 10, respectively.

Table 9. Descriptive Statistics of Data in the DID Method

Time variable	Year	Control (Treat = 0)	Treatment (Treat = 1)
Firm		611	505

Source: Stata output.

Table 10 shows a balanced distribution of the sample, with 611 observations in the control group (Treat = 0) and 505 observations in the treatment group (Treat = 1). Clearly distinguishing the control and treatment groups using the treatment indicator is essential for accurately evaluating the causal effect within the DID framework. The adequate number of observations in both groups ensures the reliability of the conclusions regarding the impact of the Paris Agreement on environmental pollution.

Table 10. DID Method Results

	Coefficient	S. Err.	t	P > |t|
DID	−0.634	0.230	2.76	0.006***

Note: *, ** and, *** denote statistical significance at the 1%, 5%, and 10% levels, respectively

Source: Stata output.

Table 10 presents the estimation results of the DID model for environmental pollution. The DID coefficient is negative and statistically significant at the 1% level. This implies that the environmental pollution reduction effect after the signing of the Paris Agreement is significantly stronger for countries with a high level of financial inclusion.

Based on the analysis results from the DID method, this research further reinforces the study's findings by accepting hypothesis H_3. This affirms that the Paris Agreement genuinely influences the impact of financial inclusion on the environment. This finding demonstrates that a nation's commitment to and implementation of the Paris Agreement's objectives creates a significant change in how financial inclusion affects environmental pollution. In other words, this result implies that the Paris Agreement is not merely a simple environmental accord, but a crucial factor in reshaping the relationship between financial inclusion and the goal of sustainable environmental development in member countries.

Discussion

The empirical results provide robust evidence that the relationship between financial inclusion and environmental pollution is nonlinear, confirming the existence of a threshold effect. Specifically, financial inclusion initially increases pollution levels, but the effect changes direction once the inclusion index surpasses the threshold. This finding aligns with the EKC framework, which postulates an inverted U-shaped relationship between economic development and environmental degradation (Tan, Lean, and Khan 2014; Ali et al. 2021).

This result is consistent with Renzhi and Baek (2020), who also reported a nonlinear relationship between financial inclusion and environmental performance, suggesting that inclusive finance can be an effective tool for pollution mitigation when it reaches a certain level of maturity. Similarly, Le, Le, and Taghizadeh-Hesary (2020) found that financial inclusion contributes to emission reduction in the long run once economies develop robust financial systems that promote green investments.

However, the current study diverges from Rehman, Fareed and Shahzad (2022) and Hussain et al. (2024), who found a positive and linear relationship between financial inclusion and environmental

pollution in Asia. The difference may arise from the methodological approach unlike these studies, our analysis employs a panel threshold regression, which captures nonlinearity and identifies critical levels of financial inclusion, and a DID model to account for cross-country heterogeneity.

Regarding the moderating factors, the DID results reveal that both national income and participation in the Paris Agreement significantly influence the environmental outcomes of financial inclusion. Higher-income countries or early participation in the Paris Agreement experience a stronger pollution-reducing effect. This finding supports Chaudhry, Yusop, and Habibullah (2022) and Du et al. (2022), who argued that institutional quality and environmental regulation determine how financial inclusion translates into environmental benefits. It also extends the conclusions of Amin, Song, and Khan (2022) by showing that the positive environmental impact of financial inclusion depends on country-specific policy frameworks and international commitments.

Overall, the results confirm that financial inclusion alone is not a guaranteed path to environmental sustainability. Its effectiveness depends on reaching a certain level of financial development, coupled with strong environmental governance. Therefore, this study contributes to the literature by:

1. Empirically identifying the threshold point at which financial inclusion becomes environmentally beneficial.
2. Highlighting the conditional role of income and international environmental commitments in shaping the inclusion–pollution nexus.
3. Providing policy-oriented insights for promoting inclusive yet environmentally sustainable financial systems.

Unlike most previous studies that view financial inclusion as a linear determinant of environmental outcomes, this research reveals a dynamic mechanism where the composition and maturity of financial inclusion matter. The findings show that inclusive finance exerts a dual effect: it can either exacerbate or alleviate pollution depending on the balance between credit expansion and green investment facilitation. By identifying a quantifiable threshold value and testing cross-country heterogeneity through the DID model, this study provides a novel empirical contribution to the environmental finance literature.

Conclusions

This study examined how financial inclusion affects environmental pollution across 61 developing countries between 2005 and 2022, employing both the Panel Threshold Regression (PTR) and Difference-in-Differences (DID) models. The research aimed to identify nonlinear relationships, as well as the moderating roles of national income and participation in the Paris Agreement.

The empirical findings provide strong support for Hypothesis H1, confirming the existence of a nonlinear (threshold) effect between financial inclusion and environmental pollution. Specifically, financial inclusion increases CO_2 emissions at lower levels, but its impact changes direction once it surpasses the threshold, meaning that greater financial inclusion contributes to reducing

environmental pollution beyond this point. This evidence supports the Environmental Kuznets Curve (EKC) framework and highlights that the environmental benefits of financial inclusion only materialize beyond a certain level of financial development.

Hypothesis H2 is also confirmed. The DID results indicate that national income significantly moderates the financial inclusion–pollution relationship. In higher-income countries, financial inclusion plays a more effective role in promoting green investment and cleaner production, while in lower-income countries, expanding financial access still tends to increase emissions due to energy-intensive industrialization.

Similarly, Hypothesis H3 is validated. Participation in the Paris Agreement strengthens the environmental benefits of financial inclusion. Countries that joined the Agreement earlier, or have stronger environmental governance, experience a more pronounced reduction in CO_2 emissions when financial inclusion expands. This finding underscores the importance of global environmental commitments in enabling inclusive finance to support sustainability.

Taken together, these results reveal that financial inclusion can either exacerbate or mitigate environmental pollution depending on its level of development and the broader economic–policy context. The study contributes to the existing literature by:

1. Identifying the threshold level of financial inclusion at which its environmental impact changes direction.
2. Demonstrating the moderate effects of income and international environmental commitments.
3. Integrating the PTR and DID frameworks to provide a more comprehensive understanding of the inclusion–environment nexus.

From a policy perspective, the findings suggest that developing countries should not treat financial inclusion as an end. Instead, they should align financial inclusion strategies with environmental objectives, focusing on green credit, sustainable investment, and inclusive financial technologies that promote carbon dioxide reduction. Strengthening international cooperation under the Paris Agreement framework can further amplify the positive environmental effects of financial inclusion.

Despite its empirical contributions, this study has several limitations that open avenues for future research.

First, the measurement of financial inclusion relies primarily on traditional indicators such as the number of bank branches and ATMs, due to data availability across developing countries. These indicators may not fully capture the current technological dimension of financial inclusion, such as digital payments, mobile banking, and fintech development. Future studies should incorporate digital financial indicators to better reflect the impact of financial innovation on environmental outcomes.

Second, the analysis focuses on the economic and financial channels through which inclusion affects environmental pollution, but it does not explicitly account for institutional or governance

factors that could moderate this relationship. Including these variables could enhance understanding of how institutional quality strengthens or weakens the environmental effectiveness of inclusive finance.

Third, the study uses the timing of Paris Agreement participation as a proxy for environmental commitment. While this captures differences in the adoption of climate policies, future work could employ more granular indicators, such as domestic green finance regulations, environmental stringency indices, or national climate policy scores, to capture policy heterogeneity more precisely.

Addressing these limitations will allow future research to develop a more comprehensive understanding of how inclusive financial systems contribute to sustainable and low-carbon development. Future studies should also incorporate direct measures of financial literacy and digital financial access to disentangle their specific environmental impacts.

References

Ahamed, M.M., Mallick, S.K. (2019), *Is financial inclusion good for bank stability? International evidence*, "Journal of Economic Behavior & Organization", 157, pp. 403–427, https://doi.org/10.1016/j.jebo.2017.07.027

Ali, S., Dogan, E., Chen, F., Khan, Z. (2021), *International trade and environmental performance in top ten-emitters countries: The role of eco-innovation and renewable energy consumption*, "Sustainable Development", 29 (2), pp. 378–387.

Alola, A.A., Bekun, F.V., Sarkodie, S.A. (2019), *Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe*, "Science of the Total Environment", 685, pp. 702–709, https://doi.org/10.1016/j.scitotenv.2019.05.139

Amin, N., Song, H., Khan, Z.A. (2022), *Dynamic linkages of financial inclusion, modernization, and environmental sustainability in South Asia: a panel data analysis*, "Environmental Science and Pollution Research", 29 (11), pp. 16588–16596, https://doi.org/10.1007/s11356-021-16648-7

Baloch, M.A., Ozturk, I., Bekun, F.V., Khan, D. (2021), *Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: Does globalization matter?*, "Business Strategy and the Environment", 30 (1), pp. 176–184, https://doi.org/10.1002/bse.2615

Baloch, M.A., Wang, B. (2019), *Analyzing the role of governance in CO_2 emissions mitigation: The BRICS experience*, "Structural Change and Economic Dynamics", 51, pp. 119–125, https://doi.org/10.1016/j.strueco.2019.08.007

Charfeddine, L., Mrabet, Z. (2017), *The impact of economic development and social-political factors on ecological footprint: A panel data analysis for 15 MENA countries*, "Renewable and Sustainable Energy Reviews", 76, pp. 138–154, https://doi.org/10.1016/j.rser.2017.03.031

Chaudhry, I.S., Yusop, Z., Habibullah, M.S. (2022), *Financial inclusion-environmental degradation nexus in OIC countries: new evidence from environmental Kuznets curve using DCCE approach*, "Environmental Science and Pollution Research", 29 (4), pp. 5360–5377, https://doi.org/10.1007/s11356-021-15941-9

Chibba, M. (2009), *Financial Inclusion, Poverty Reduction and the Millennium Development Goals*, "The European Journal of Development Research", 21 (2), pp. 213–230, https://doi.org/10.1057/ejdr.2008.17

Dou, D., Li, L. (2022), *Does sustainable financial inclusion and energy efficiency ensure green environment? Evidence from BRICS countries*, "Economic Research – Ekonomska istraživanja", 35 (1), pp. 5599–5614, https://doi.org/10.1080/1331677X.2022.2032785

Du, Q., Wu, N., Zhang, F., Lei, Y., Saeed, A. (2022), *Impact of financial inclusion and human capital on environmental quality: evidence from emerging economies*, "Environmental Science and Pollution Research", 29 (22), pp 33033–33045, https://doi.org/10.1007/s11356-021-17945-x

Frankel, J.A., Romer, D. (2017), *Does Trade Cause Growth?*, [in:] J.J. Kirton (ed.), *Global Trade*, Routledge, London, pp. 255–276, https://doi.org/10.4324/9781315254166-11

Gill, A.R., Hassan, S., Haseeb, M. (2019), *Moderating role of financial development in environmental Kuznets: a case study of Malaysia*, "Environmental Science and Pollution Research", 26 (33), pp. 34468–34478, https://doi.org/10.1007/s11356-019-06565-1

Gupte, R., Venkataramani, B., Gupta, D. (2012), *Computation of Financial Inclusion Index for India*, "Procedia-Social and Behavioral Sciences", 37, pp. 133–149, https://doi.org/10.1016/j.sbspro.2012.03.281

Hansen, B.E. (2000), *Sample Splitting and Threshold Estimation*, "Econometrica", 68 (3), pp. 575–603, https://doi.org/10.1111/1468-0262.00124

Hussain, S., Ahmad, T., Ullah, S., Rehman, A.U., Shahzad, S.J.H. (2024), *Financial inclusion and carbon emissions in Asia: Implications for environmental sustainability*, "Economic and Political Studies", 12 (1), pp. 88–104, https://doi.org/10.1080/20954816.2023.2273003

Le, T.H., Le, H.C., Taghizadeh-Hesary, F. (2020), *Does financial inclusion impact CO_2 emissions? Evidence from Asia*, "Finance Research Letters", 34, 101451, https://doi.org/10.1016/j.frl.2020.101451

Liu, N., Hong, C., Sohail, M.T. (2022), *Does financial inclusion and education limit CO_2 emissions in China? A new perspective*, "Environmental Science and Pollution Research", 29 (13), pp. 18452–18459, https://doi.org/10.1007/s11356-021-17032-1

Pesaran, M.H. (2004), *General Diagnostic Tests for Cross Section Dependence in Panels*, "Cambridge Working Papers, Economics", 1240 (1), 1, https://doi.org/10.2139/ssrn.572504

Qin, L., Raheem, S., Murshed, M., Miao, X., Khan, Z., Kirikkaleli, D. (2021), *Does financial inclusion limit carbon dioxide emissions? Analyzing the role of globalization and renewable electricity output*, "Sustainable Development", 29 (6), pp. 1138–1154, https://doi.org/10.1002/sd.2208

Rehman, M.A., Fareed, Z., Shahzad, F. (2022), *When would the dark clouds of financial inclusion be over, and the environment becomes clean? The role of national governance*, "Environmental Science and Pollution Research", 29 (19), pp. 27651–27663, https://doi.org/10.1007/s11356-021-17683-0

Renzhi, N., Baek, Y.J. (2020), *Can financial inclusion be an effective mitigation measure? Evidence from panel data analysis of the environmental Kuznets curve*, "Finance Research Letters", 37, 101725, https://doi.org/10.1016/j.frl.2020.101725

Sarma, M. (2008), *Index of Financial Inclusion*, "Working Paper", 215, Indian Council for Research on International Economic Relations (ICRIER), New Delhi, https://www.icrier.org/pdf/Working_Paper_215.pdf (accessed: 11.09.2025).

Sarma, M. (2016), *Measuring Financial Inclusion for Asian Economies*, [in:] S. Gopalan, T. Kikuchi (eds.), *Financial Inclusion in Asia*, Springer, London, pp. 3–34, https://doi.org/10.1057/978-1-137-58337-6_1

Sarma, M., Pais, J. (2008), *Financial Inclusion and Development: A Cross Country Analysis*, https://icrier.org/pdf/Mandira%20Sarma-Paper.pdf (accessed: 11.09.2025).

Sarma, M., Pais, J. (2011), *Financial Inclusion and Development*, "Journal of International Development", 23 (5), pp. 613–628, https://doi.org/10.1002/jid.1698

Tamazian, A., Chousa, J.P., Vadlamannati, K.C. (2009), *Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries*, "Energy Policy", 37 (1), pp. 246–253, https://doi.org/10.1016/j.enpol.2008.08.025

Tan, F., Lean, H.H., Khan, H. (2014), *Growth and environmental quality in Singapore: Is there any trade-off?*, "Ecological Indicators", 47, pp. 149–155, https://doi.org/10.1016/j.ecolind.2014.04.035

Wang, X., Wang, X., Ren, X., Wen, F. (2022), *Can digital financial inclusion affect CO_2 emissions of China at the prefecture level? Evidence from a spatial econometric approach*, "Energy Economics", 109, 105966, https://doi.org/10.1016/j.eneco.2022.105966

Zaidi, S.A.H., Hussain, M., Zaman, Q.U. (2021), *Dynamic linkages between financial inclusion and carbon emissions: Evidence from selected OECD countries*, "Resources, Environment and Sustainability", 4, 100022, https://doi.org/10.1016/j.resenv.2021.100022

Jak inkluzja finansowa wpływa na zanieczyszczenie środowiska: zastosowanie modelu regresji progowej i metody DID

W niniejszym badaniu poddano analizie nieliniowy wpływ inkluzji finansowej na zanieczyszczenie środowiska w 61 krajach rozwijających się w latach 2005–2022. Wykorzystanie modelu regresji progowej pozwala na wskazanie krytycznego progu, przy którym kierunek wpływu inkluzji finansowej na zanieczyszczenie środowiska ulega zmianie. Poniżej tego progu inkluzja finansowa ma tendencję do zwiększania emisji dwutlenku węgla, jednak po jego przekroczeniu relacja się odwraca, a inkluzja finansowa przyczynia się do redukcji zanieczyszczeń. Aby uzyskać głębszy wgląd w zagadnienie, w badaniu dodatkowo zastosowano metodę *Difference-in-Differences* (DID). Jej użycie pokazuje, że efekt inkluzji finansowej jest zróżnicowany i zależy od poziomu rozwoju finansowego, dochodu narodowego oraz momentu przystąpienia danego kraju do Porozumienia paryskiego w sprawie zmian klimatu.

Ustalenia zawarte w artykule podkreślają wielowymiarowy charakter relacji między inkluzją finansową a środowiskiem, która jest w znacznym stopniu kształtowana przez czynniki ekonomiczne i polityczne, specyficzne dla danego kraju. Ponadto badanie wykazało, że dochód narodowy i poziom urbanizacji wiążą się ze wzrostem zanieczyszczeń, podczas gdy kredyty dla sektora prywatnego odgrywają rolę łagodzącą w procesie redukcji emisji.

Wyniki niniejszego badania mają istotne implikacje, które decydenci powinni uwzględnić przy projektowaniu strategii promujących inkluzję finansową w zgodzie z celami zrównoważonego rozwoju.

Słowa kluczowe: inkluzja finansowa, zanieczyszczenie środowiska, metoda DID, metoda panelowa regresji progowej

Comparative Economic Research. Central and Eastern Europe
Volume 29 Number 1, 2026
https://doi.org/10.18778/1508-2008.29.07

Determinants of Fintech Fundraising in Europe

Katarzyna Niewińska https://orcid.org/0000-0002-0902-7491
Ph.D., University of Warsaw, Warsaw, Poland, e-mail: kniewinska@wz.uw.edu.pl

Abstract

The study examines how the sub-indices of the Global Innovation Index (GII) affect the total value of fintech (financial technology) start-up fundraising in thirty-five European countries, including an eleven-country subsample from Central and Eastern Europe (CEE). Using annual panel data for 2013–2022. Fixed-effects models were estimated for the full sample, while random-effects models were used for the CEE countries. In these models, total fintech fundraising is the dependent variable, and the five GII subindices are the independent variables. The coefficients for Knowledge Workers, Knowledge Impact, and Business Environment are negative and statistically significant, and their effect sizes are even larger in the CEE subsample. The results suggest that improvements in the analysed factors do not necessarily lead to increased market funding for start-ups. The findings indicate that strengthening these dimensions of innovation does not automatically boost market funding for fintech start-ups. The study enriches the fintech fundraising literature by showing that improvements in the analysed factors do not translate into greater market funding for start-ups. As the study is limited to European data from 2013 to 2022, future research could extend the geographic scope or incorporate additional variables.

Keywords: fintech, fundraising, venture capital, fintech investment, innovation ecosystem
JEL: G24, J24, O32

Funding information: University of Warsaw, Warsaw, Poland.
Declaration regarding the use of GAI tools: Not used.
Conflicts of interests: None.
Ethical considerations: The Author assures of no violations of publication ethics and takes full responsibility for the content of the publication.
Received: 17.07.2025. Verified: 20.10.2025. Accepted: 29.01.2026

Introduction

The fintech (financial technology) start-up market developed at an impressive pace after the Global Financial Crisis (GFC) and achieved remarkable results until 2021. This was evident in the increasing scale of funding for this sector across Europe, the United States, and Asia. In particular, 2021 was a breakthrough year, as record levels of funding were reached for fintech start-ups through Venture Capital (VC) funds. It was a year marked not only by the highest amounts of capital raised but also by a record number of transactions and a significant number of mega funding rounds. However, since 2022, there has been a noticeable return to the funding levels observed before 2021 (CB Insights 2022; 2024), with a reduction in the amount of investment capital directed toward new technologies in the financial industry. The 2022 fintech fund-raising downturn coincided with rapid policy-rate hikes that tightened financial conditions and curtailed venture capital activity, especially late-stage and non-traditional participation (Atomico 2023; European Central Bank 2023). Globally, venture capital investment decreased by approximately 35 per cent in 2022 and continued to be subdued in 2023 (CB Insights 2024). In Europe, aggregate investment in 2023 was projected to be around 45 billion dollars, significantly below the levels recorded in 2021.

Understanding what drives fintech fundraising in Europe matters for public policymakers, who must target scarce innovation resources and regulatory effort. Knowing which parts of a country's innovation system convert into private capital for startups, and which do not, guides proportionate rules, entrepreneurship support, public co-investment, data access, and education. It also helps anticipate shifts of capital toward other tech sectors. France's Plan Tibi, led by Professor Philippe Tibi, shows how policy can mobilise institutional investors for technology firms (Direction générale du Trésor 2024; 2025). This study links Global Innovation Index (GII) sub-indices with observed fintech fundraising across Europe, including Central and Eastern Europe (CEE), to demonstrate the relationship between scores on specific dimensions and the total amount of fundraising in the fintech sector.

The development of the fintech industry is driven by enabling technologies, most notably the extensive application of artificial intelligence, blockchain, and 5G (Saiyed 2025). As a result, enterprises in this sector are increasingly adopting artificial intelligence (AI) solutions (Zhang, Ashta, and Barton 2021; Jain, Prajapati, and Dangi 2023). AI is revolutionising the strategic operations of financial institutions by compelling them to be more open and collaborative (Ashta and Herrmann 2021). Fintech companies use these technologies to develop new services, including providing AI as a service to financial institutions (Zhang, Ashta, and Barton 2021). These offerings primarily include credit scoring, where multiple data points streamline decision-making and mitigate default risk, and fraud detection and prevention (including AML – Anti-Money Laundering and KYC – Know Your Customer). They also include investment advice, where recommendation algorithms use market data and investor preferences, and automated customer support systems based on chatbots and conversational interfaces that facilitate user interactions. In addition, AI applications are widely used in personal financial management (Maple et al. 2023; Kamuangu 2024; Priyanka 2024; Saiyed 2025). Fintechs compete based on the quality of their solutions, including the ability to implement machine learning

(Zhang, Ashta, and Barton 2021; Maple et al. 2023; World Economic Forum 2025), which directly affects their ability to attract capital.

Existing cross-country studies show that fintech activity and funding are associated with measures of innovation capacity (Haddad and Hornuf 2019; Laidroo and Avarmaa 2020; Cojoianu et al. 2023) and institutional quality (including regulatory frameworks) (Claessens et al. 2018; Cornelli et al. 2021; 2024) and venture capital availability (Cumming and Schwienbacher 2018; Haddad and Hornuf 2019; Kolokas et al. 2022). At the same time, the World Bank's (2022) report points to large cross-regional heterogeneity and the possibility that the same enabling conditions may support other technology sectors more than fintech, especially in smaller or emerging economies. While this strand of the literature has significantly improved our understanding of the macroeconomic, technological, and institutional determinants of fintech activity, several specific gaps remain. Many cross-country measures capture activity or adoption rather than equity fundraising (World Bank 2022; Golder et al. 2025).

The World Bank's composite Fintech Activity Index itself notes measurement constraints, a cross-sectional design and the exclusion of fast-evolving segments (World Bank 2022). In addition, the enabling environment is usually captured through a relatively narrow set of indicators such as GDP *per capita* (Ivanova et al. 2017), venture capital intensity (Kolokas et al. 2022; Alaassar, Mention, and Aas 2023) or internet penetration, instead of analysing national innovation systems as multidimensional configurations of institutions, human capital, infrastructure, market sophistication, and business sophistication (Ryu 2025). Similarly, Haddad and Hornuf (2019) explain fintech emergence using GDP, venture capital availability, and digital infrastructure indicators, reflecting a macroeconomic rather than systemic view of innovation. Global evidence on fintech equity funding also relies on aggregated patterns and macro-level drivers, providing only limited region-specific insights for Europe, particularly for CEE (Cornelli et al. 2021). While regional analyses confirm that contextual factors shape fintech development, they seldom link these conditions to cross-country differences in fundraising outcomes within subregions (Zarrouk, Ghak, and Bakhouche 2021).

These gaps highlight a research problem: despite extensive evidence on the macroeconomic and institutional drivers of fintech activity (Cumming and Schwienbacher 2018; Haddad and Hornuf 2019; Cornelli et al. 2021), there is limited understanding of whether improvements in innovation system components, such as business environment, human capital, investment conditions, and knowledge creation, translate into greater equity fundraising for fintech start-ups (Van Roy and Nepelski 2017; Cojoianu et al. 2023; World Intellectual Property Organization 2023b). Existing research seldom examines how these multidimensional factors shape the fundraising landscape across European economies or whether their effects differ between advanced and emerging innovation contexts such as CEE (Cornelli et al. 2021; Zarrouk, Ghak, and Bakhouche 2021; Kolokas et al. 2022).

The main aim of this study is to examine the association between four GII subindices (Business Environment, Education, Knowledge Workers, Knowledge Impact) and the total value of fintech fundraising across 35 European economies from 2013 to 2022, including a CEE subsample.

The fintech literature has expanded rapidly in recent years (Milian, Spinola, and Carvalho 2019; Kumari and Chitra Devi 2022; Niewinska 2023), mostly highlighting the sector's transformative impact on traditional financial services (Gomber, Koch, and Siering 2017; Moccia, Passerini, and Tomic 2018; Natarajan 2020; Cornelli et al. 2021; Harasim 2021). Research has emphasised the role of innovation in driving fintech growth, particularly in terms of knowledge workers and technological output (Haddad and Hornuf 2019). A detailed citation analysis by Cumming, Johan, and Reardon (2023) revealed research gaps and emerging trends that link international business and fintech, underscoring the need for further exploration in this domain. (Haddad and Hornuf 2019) also found that the key factors for the successful emergence and funding of fintech start-ups were centred on well-developed economies and readily available venture capital. This analysis provides a better understanding of how GII factors affect the fundraising landscape in the European fintech sector.

The paper is structured as follows. Section 2 develops the theoretical background, while Section 3 provides related empirical evidence. Section 4 presents the data and methods, Section 5 reports results, Section 6 discusses implications, and Section 7 concludes.

Theoretical background

Several strands of economic and management theory (Freeman 1995; Hall and Soskice 2001; Audretsch and Keilbach 2007; Lundvall 2007; Spigel 2017) provide a foundation for examining how a country's innovation environment influences fintech fundraising (Jeng and Wells 2000; Hall and Soskice 2001). In particular, this study draws on Innovation Systems Theory, the Entrepreneurial Ecosystem perspective, Institutional Theory (North 1990; Freeman 1995; OECD 2002; Lundvall 2007), and the resource-based view (RBV) from strategic management and venture capital perspectives (Cumming and Schwienbacher 2018; Da Rin and Penas 2019; Jeng and Wells 2000; Hall and Soskice 2001; Kolokas et al. 2022; Turki and Rieg 2023). Collectively, these frameworks suggest that a country's innovation environment, encompassing its human capital, knowledge production, business environment, and institutional quality, plays a critical role in shaping entrepreneurial outcomes, such as startup funding (Etzkowitz and Leydesdorff 2000; Jeng and Wells 2000; OECD 2002; World Intellectual Property Organization 2023b). This section outlines each theoretical lens and links it to the study's research problems, which posit that GII sub-indices (Knowledge Workers, Knowledge Impact, Business Environment, Education) determine fintech fundraising.

Innovation Systems Theory

Innovation Systems Theory conceptualises innovation outcomes as the result of systemic interactions among firms, universities, and government institutions, rather than isolated firm-level efforts (Freeman 1995; OECD 2002; Lundvall 2007). Innovation capacity depends on the coherence and complementarity of knowledge production, education systems, and industrial application (Nelson 1993; Edquist 2009). In this view, entrepreneurial success depends not only on technological inputs but also on the alignment between scientific, regulatory, and market subsystems (Etzkowitz and Leydesdorff 2000; Al-Mannaei et al. 2023). For fintech, this implies

that human capital and innovation outputs must operate within enabling financial and regulatory contexts to generate investable opportunities (Tello-Gamarra et al. 2022; Bhutto, Jamal, and Ullah 2023; Baig et al. 2025). The link to this study is direct: the GII sub-indices of Education, Knowledge Workers, and Knowledge Impact capture central input–output components of national innovation systems, while Business Environment reflects the institutional infrastructure needed to mobilise and commercialise these capabilities (OECD 2002). Systems theory also anticipates outcome heterogeneity across countries, since similar innovation inputs can yield different sectoral results depending on the quality of linkages and the absorptive capacity of entrepreneurial actors (Tödtling and Trippl 2005; Audretsch and Keilbach 2007).

Institutional Theory

Institutional theory sees institutions as the formal rules and their enforcement that shape incentives and reduce uncertainty for economic actors (North 1990). When laws are clear, contracts are enforced, and regulation is predictable, investors face lower risk and lower transaction costs, so they are more willing to finance young firms (Jeng and Wells 2000; Cumming and Schwienbacher 2018). The Business Environment sub-indices can serve as a country-level proxy for these conditions because they reflect ease of entry, investor protection, and regulatory quality (OECD 2002).

Resource-Based View (RBV) and strategic management

The Resource-Based View (RBV) theory explains sustained performance by the possession and deployment of resources and capabilities that are valuable, rare, and difficult to imitate, and by an organisation that enables value capture (Wernerfelt 1984; Barney 2001; Bömer and Schwienbacher 2018). In entrepreneurial finance, investors allocate capital to ventures that credibly assemble such resource bundles, while venture capital helps discover and scale them through screening, staging, and value-adding support that reduces uncertainty (Gompers and Lerner 1996; Jeng and Wells 2000). When applied to fintech, salient resources include specialised finance and software skills, data and analytical know-how, and routines for rapid product iteration. Evidence shows that locations that combine strong financial institutions with strong software industries attract more venture investments in fintech (Bömer and Schwienbacher 2018). In our framework, Education and Knowledge Workers proxy the national stock of talent as core resources, Knowledge Impact captures the translation of research into outputs that investors can evaluate, and Business Environment reflects frictions that determine whether these resources are mobilised into equity fundraising.

Related empirical evidence

Building on the above theories, the following sections review the empirical evidence on fintech fundraising around three thematic drivers: (1) institutional quality and regulatory environment, (2) knowledge, innovation and human capital factors, and (3) market structure and financial ecosystem factors. The literature shows that these drivers shape the volume of equity raised by fintech start-ups (Cumming and Schwienbacher 2018; Cornelli et al. 2021; Cojoianu et al. 2023).

Institutional quality and regulatory environment

Empirical studies link stronger legal and regulatory environments with higher fintech investment. Scholars emphasise that better regulations and higher-quality institutional governance are conducive to greater investments in fintech companies. Investments in this sector have grown dynamically since 2010 in countries characterised by a higher capacity for innovation and better legal and regulatory infrastructure (Cornelli et al. 2021). At the same time, earlier studies by La Porta and Shleifer (2008) and Demirgüç-Kunt and Levine (2018) emphasise the importance of the rule of law and the quality of institutions for the overall level of investment in the financial sector. The introduction of mechanisms such as regulatory sandboxes has a positive impact on the fundraising potential of fintech companies, favouring innovation and investment. Firms admitted to regulatory sandboxes raise 15% more capital and are roughly 50% more likely to secure funding relative to comparable firms outside the sandbox (Cornelli et al. 2021; 2024). These findings align with institutional theory and support treating Business Environment (BE) as a country-level proxy for institutional quality in fundraising analyses.

RQ1: Is the quality of the business environment (BE) associated with the total value of fintech deals?

Knowledge, Innovation, and Human Capital Factors (Knowledge Spillovers)

Evidence indicates that the creation and diffusion of technological knowledge are central to fintech emergence and financing. According to Cojoianu et al. (2023), the creation and diffusion of technological knowledge (e.g., in the IT sector) is crucial for the emergence and development of fintech start-ups. This corresponds to the Theory of Knowledge Spillover Entrepreneurship, which posits that new ventures commercialise locally generated knowledge, converting it into entrepreneurial outcomes and investment (Audretsch and Keilbach 2007). However, in some cases, high labour costs and the unique conditions of the local market may limit the scale of funding, which indicates the complexity of the relationship between the availability of highly qualified specialists and the amount of funds raised. The business environment and the level of trust in incumbent financial institutions also affect the scale of investment. Low levels of trust may encourage entrepreneurs to seek innovative solutions. At the same time, historically distrustful regions tend to attract less capital (Cojoianu et al. 2023). In the context of key competencies, it is emphasised that experience in finance and IT has a greater consequence for fintech success than experience in the banking sector (Turki and Rieg 2023). In Poland, uncertainty about the availability of qualified employees and the lack of appropriate legal regulations have proven a particular barrier to development (Kliber et al. 2021). These insights motivate modelling Education (E), Knowledge Workers (KW) and Knowledge Impact (KI) as separate innovation dimensions linked to fundraising.

RQ2: Is a country's education level (E) associated with the total value of fintech deals?

RQ3: Are knowledge workers (KW) associated with the total value of fintech deals?

RQ4: Is knowledge impact (KI) associated with the total value of fintech deals?

Market structure and entrepreneurial finance

Market structure shapes how institutional and knowledge conditions translate into capital flows. Several other factors that shape fintech ecosystems are also highlighted in the literature. For example, countries with well-developed economies and easily accessible venture capitalists have more fintech start-ups (Haddad and Hornuf 2019). In turn, greater difficulties in accessing bank loans favour the development of fintech companies in a given country (Haddad and Hornuf 2019). The volume of investment in innovative sectors (including fintech) is also significantly influenced by macroeconomic factors such as GDP growth (Kassner 2024). Early-stage investor presence matters for the funding path. Fintech firms backed at seed or by angel investors are more likely to raise follow-on rounds, while single-founder start-ups face lower fundraising odds (Herck Giaquinto and Bruscato Bortoluzzo 2020). Interactions with incumbents are also relevant. Acquisitions by large banks can have a positive impact on fundraising, especially in the early stages of fintech development, whereas similar decisions taken by large technology corporations usually do not result in similar growth (Cornelli et al. 2021). These patterns imply that the effect of institutional and knowledge drivers will differ across European subregions with distinct investor bases and financial structures.

RQ5: Do these associations differ in magnitude between CEE and the rest of Europe?

Synthesis and regional heterogeneity in Europe

The literature confirms that fintech development and fundraising are shaped by multiple determinants. Institutional and regulatory quality, together with a supportive business environment, are central to investment outcomes (Demirgüç-Kunt and Levine 2018; Cornelli et al. 2021). It is evident that knowledge creation, human capital, and IT capabilities are particularly relevant for fundraising in the fintech sector (Audretsch and Keilbach 2007; Cojoianu et al. 2023). Furthermore, trust in incumbent financial institutions is instrumental in determining how knowledge spillovers translate into entrepreneurial finance (Audretsch and Keilbach 2007; Khlystova, Kalyuzhnova, and Belitski 2022; Cojoianu et al. 2023). The emphasis is placed not only on the relevance of regulations regarding the fintech sector and human capital, but also on the role of macroeconomic conditions, trust in traditional financial services, and the capacity of innovative organisations to attract funding (Alaassar, Mention, and Aas 2021; Vijayagopal, Jain, and Viswanathan 2024; Al-Assaf, Abdel-Halim, and Shehadeh 2025). All the above points to the need for a more integrated and multidimensional approach to examining factors that are conducive to the development and financing of fintech companies in Europe. Market structure further shapes transmission channels through venture capital depth, bank-credit constraints, and the presence of early investors and exit routes (Haddad and Hornuf 2019; Herck Giaquinto and Bruscato Bortoluzzo 2020; Cornelli et al. 2021). Evidence from the European Union shows that better access to financing, limited bureaucracy, a coherent political system, a favourable entrepreneurship education system, and high-quality protection of intellectual property rights tend to be associated with a greater share of high-tech companies (Van Roy and Nepelski 2017). Cross-regional analyses also point to substantial heterogeneity in the effectiveness of enabling conditions, which motivated us to test whether the associations documented above differ between CEE and the rest of Europe (World Bank 2022).

Data and methodology

The main aim of this study is to identify the factors that influence the total size of deals by fintech companies in European countries and in the CEE region. The methodology employed was a regression model applied to a panel dataset containing annual data from 2013 to 2022 for different European countries. The dependent variable is total deal size, measured in millions of USD, which represents the total amount of money raised by fintech companies in a given country and year. The independent variables are derived from the GII and include sub-indices related to business environment, education, investment, knowledge workers, and knowledge impact.

Dependent variables

The dependent variable in this study is the total value of capital raised by companies in the fintech sector in a given country and year (Total deal size – name of variable: TOTALDEALS). Data were obtained from the PitchBook database using the following filters: companies were selected from the "Analyst-Curated Verticals: FinTech" category, taking into account entities founded in the period between 2009 and 2023, while the limitation of data from independent variables resulted in the extraction of annual data for 35 European countries in the period 2013–2022. Total funding is expressed in millions of US dollars and represents the amount of funds raised in a given year by the fintech sector in each of the analysed countries. This variable allows us to assess the scale of funding provided to innovative financial ventures and shows the pace of development of the fintech market in individual countries.

Independent variables

Selected sub-indices from the GII developed and published by the WIPO served as the independent variables. Each variable reflects a different dimension of innovation potential and conditions that are conducive to the creation and development of new technologies through the financing of companies in the fintech sector. This will allow us to capture the complexity and assess whether better quality education, business ecosystem, investment, and knowledge affect the level of financing (World Intellectual Property Organization 2023a).

Business Environment (name of variable: BE) – a variable from the institution index group. It considers various aspects related to the quality of the institutional environment, such as starting a business, investor protection regulations, and the efficiency and effectiveness of solving problems related to enterprise insolvency. Better institutional conditions contribute to the development of entrepreneurship and attract capital, creating a favourable environment for entities from the fintech sector.

Education (name of variable: E): a variable from the Human Capital and Research index group that focuses on the quality and scope of the educational system. It considers, *inter alia*, expenditure on education, school life expectancy, results in international tests (e.g., PISA), and the available funding per student. A high level of education and an extensive base of human capital are conducive to devising innovative solutions whose adoption and commercialisation – also in the fintech sector – depend on the availability of highly qualified staff.

Investment (name of variable: I): a variable from the Market Sophistication index group that covers market conditions and dynamics, including the effective protection of minority investors and the level of investment activity (e.g., VC investments). Greater market sophistication translates into better conditions for raising capital for innovative ventures, including fintech companies, thus creating a favourable environment for the development of new business models.

Knowledge Workers (name of variable: KW): A variable from the Business Sophistication index group that relates to the intensity of intellectual capital and level of advancement of the business sector. It considers the availability of highly qualified workers, employment in knowledge-based sectors, research and development (R&D) expenditure, and the employment of women with higher education. Greater business sophistication indicates the possibility of fintech companies effectively creating, testing, and implementing innovations, which may translate into greater funding.

Knowledge Impact (name of variable: KI): a variable from the knowledge and technology output index group. It measures the effectiveness of innovation processes, considering, *inter alia*, increased labour productivity, the dynamics of new enterprise creation, software expenditure, standards quality (ISO certifications), and the production of high-tech goods. A high level of innovation activity can stimulate the development and financing of fintech enterprises through increased market attractiveness and improved innovation infrastructure.

These independent variables are analysed jointly in terms of the impact of various aspects of the innovation environment on fintech companies' ability to raise capital.

Table 1. Main Descriptive Statistics

	Mean	Std. Dev.	min	max	N
DEALS	451.53	903.30	1.00	6 391	350
TOTALDEALS	1 444.02	4 139.91	0.03	42 125.19	350
KW	54.57	12.36	25.80	81.80	350
KI	44.04	8.86	15.60	75.30	350
BE	76.35	13.09	17.90	93.10	350
E	58.27	8.19	35.30	86.30	350
I	39.56	16.54	1.40	96.20	350
ln DEALS	4.93	1.62	0.00	8.76	350
ln TOTALDEALS	5.04	2.54	– 3.51	10.65	350
ln KW	3.97	.24	3.25	4.40	350
ln KI	3.76	.21	2.75	4.32	350
ln BE	4.31	.23	2.89	4.53	350
ln E	4.06	.14	3.56	4.46	350
ln I	3.56	.58	0.34	4.57	350

Total number of deals – DEALS, Total deal size – TOTALDEALS, Knowledge Workers – KW, Knowledge Impact – KI, Business Environment – BE, Education – E, Investment – I.

Source: own calculations.

Table 1 presents the descriptive statistics of the variables under study and reveals significant diversity among European countries in terms of fintech market activity. An analysis of the total number of deals (DEALS) shows that, while some countries saw only one transaction, others recorded as many as 6,391, with an average of around 450 per year. Similarly, there are differences in the total deal size (TOTALDEALS): the lowest annual amount was just USD 0.03 million, while the highest exceeded USD 42,125.19 million. The data for the GII indicators (Knowledge Workers – KW, Knowledge Impact – KI, Business Environment – BE, Education – E, Investment – I), measured on a scale of 0–100, also show considerable variation, with the average values as follows: 54.57 (Knowledge Workers), 44.04 (Knowledge Impact), 76.35 (Business Environment), 58.27 (Education), and 39.56 (Investment). The minimum and maximum values of these sub-indices again illustrate the high degree of variability in the conditions for innovation in the countries studied.

Given the longitudinal structure of the dataset, we analyse the impact of country-level innovation factors on fintech fundraising with panel regression techniques. The dependent variable is the natural logarithm of total deal size, ln TOTALDEALS, measured as the annual USD value of fintech fundraising rounds in each country. All five explanatory variables are likewise expressed in natural logarithms: ln KW (Knowledge Workers), ln KI (Knowledge Impact), ln BE (Business Environment), ln E (Education) and ln I (Investment). The empirical sample covers 35 European countries observed annually between 2013 and 2022. To examine regional diversity, we estimate models based on (i) the full European panel and (ii) a CEE subsample, as defined by the Organisation for Economic Co-operation and Development (OECD).

Single-equation panel models that do not include lagged endogenous terms are estimated by the Generalised Least Squares approach in two variants: fixed-effects (FE) and random-effects (RE) (Dańska-Borsiak 2011). Pearson correlation diagnostics guided the final variable set (Table 2 and Table 3). Model selection between FE and RE relies on the Hausman test, while Breusch-Pagan Lagrange multiplier tests confirm the relevance of panel estimators over pooled OLS.

To further examine potential multicollinearity among the explanatory variables, Variance Inflation Factors (VIF) were calculated for all GII sub-indices. The VIF values ranged from 1.09 to 2.04, which is well below commonly accepted thresholds. These results confirm the absence of problematic collinearity after removing the Investment (I) sub-index, which was highly correlated with the Business Environment (BE) index, as also shown in Tables 2 and 3. The complete VIF statistics are presented in Table A1 in the Appendix.

Table 2. Pearson's correlation coefficients and statistical significance for Europe

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) ln_DEALS	1.000						
(2) ln_TOTALDEALS	0.901***	1.000					
	(0.000)						
(3) ln_KW	0.572***	0.601***	1.000				
	(0.000)	(0.000)					

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(4) ln_KI	0.218***	0.117**	0.162***	1.000			
	(0.000)	(0.028)	(0.002)				
(5) ln_BE	0.253***	0.177***	0.363***	0.162***	1.000		
	(0.000)	(0.001)	(0.000)	(0.002)			
(6) ln_E	0.196***	0.267***	0.493***	−0.105*	0.162***	1.000	
	(0.000)	(0.000)	(0.000)	(0.050)	(0.002)		
(7) ln_I	0.271***	0.235***	0.439***	0.123**	0.681***	0.152***	1.000
	(0.000)	(0.000)	(0.000)	(0.022)	(0.000)	(0.004)	

*** p < 0.01, ** p < 0.05, * p < 0.1.

Source: own calculations.

Table 3. Pearson's correlation coefficients and statistical significance for the CEE region

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) ln_DEALS	1.000						
(2) ln_TOTALDEALS	0.901***	1.000					
	(0.000)						
(3) ln_KW	0.572***	0.601***	1.000				
	(0.000)	(0.000)					
(4) ln_KI	0.218***	0.117**	0.162***	1.000			
	(0.000)	(0.028)	(0.002)				
(5) ln_BE	0.253***	0.177***	0.363***	0.162***	1.000		
	(0.000)	(0.001)	(0.000)	(0.002)			
(6) ln_E	0.196***	0.267***	0.493***	−0.105*	0.162***	1.000	
	(0.000)	(0.000)	(0.000)	(0.050)	(0.002)		
(7) ln_I	0.271***	0.235***	0.439***	0.123**	0.681***	0.152***	1.000
	(0.000)	(0.000)	(0.000)	(0.022)	(0.000)	(0.004)	

*** p < 0.01, ** p < 0.05, * p < 0.1.

Source: own calculations.

Two tests are used to check the significance of the group effects in the above panel models: the Wald test and the Lagrange multiplier test. These tests assess whether the proposed research method is justified (Dańska-Borsiak 2011). Based on the results of these tests, all null hypotheses are rejected, confirming the legitimacy of using panel models with group effects (FE and RE models). Ultimately, a fixed-effects (FE) model was used in the final stage of the analysis.

The general equation used in these models is as follows:

$$\ln TOTALDEALS_{it} = \beta 0 + \beta 1 \ln KW_{it} + \beta 2 \ln KI_{it} + \beta 3 \ln BE_{it} + \beta 4 \ln E_{\mathrm{it}} + \alpha_i + \lambda_t + \varepsilon_{it}, \quad \mathbf{i} = 1, \ldots, \mathbf{N}, \mathbf{t} = 1, \ldots, \mathbf{T} \tag{1}$$

where:
$\ln TOTALDEALS_{it}$ is the natural logarithm of the total amount of capital (expressed in millions of US dollars) raised by fintech start-ups in country *i* during year *t*;
$\ln KW_{it}$ denotes the natural logarithm of the Knowledge Workers index, which captures the proportion and quality of highly skilled labour available for innovation and technology-intensive activities in a given country-year;
$\ln KI_{it}$ is the natural logarithm of the Knowledge Impact index, reflecting how effectively a country converts research and knowledge into high-tech output, productivity gains and other tangible innovation outcomes;
$\ln BE_{it}$ is the natural logarithm of the Business Environment index; this variable measures institutional and regulatory quality, including ease of doing business, investor protection and the overall strength of financial and legal infrastructure;
$\ln E_{it}$ is the natural logarithm of the Education index, summarising the breadth and quality of a country's education system, such as expenditure per student, educational attainment, and learning outcomes;
$\beta 0$ is the common intercept term;
α_i is an unobserved country-specific effect that captures time-invariant characteristics of each country;
λ_t is a year-specific effect that absorbs shocks common to all countries in a given year;
ε_{it} is the idiosyncratic error term capturing all remaining unobserved influences on fintech fundraising in country *i* and year *t*.

Results

Table 4 presents the results of panel data estimations using FE and RE specifications. These models were applied to two separate samples: the full set of 35 European countries and a subsample consisting of the 11 CEE countries, defined according to the OECD classification. The dependent variable in all models is the natural logarithm of the total size of fintech deals (ln_TOTALDEALS), while the final independent variables include the logarithms of Knowledge Workers (ln_KW), Knowledge Impact (ln_KI), Business Environment (ln_BE), and Education (ln_E). All variables were transformed using natural logarithms. The FE model was chosen for the full European sample based on the Hausman test (p = 0.000), which indicated significant correlation between the regressors and the unobserved country-specific effects. For the CEE subsample, the Hausman test result (p = 0.318) confirmed the validity of using an RE model, as no such correlation was found. Consequently, the FE model is used to interpret the European results, while the RE specification is used for the CEE countries.

Serial correlation was assessed using a Wooldridge-type test for the FE model (F = 21.93, p = 0.000), which indicated first-order dependence in the residuals. Because serial correlation affects standard

errors but not the coefficient estimates, all FE results are presented with country-clustered robust standard errors (Drukker 2003). For the CEE subsample, the random-effects model reported an AR(1) coefficient of $\rho = 0.373$. These diagnostics are summarised in Table 4 below.

The findings from these four regressions allow us to address the following research questions:

RQ1: Does the size of fintech finance deals depend on the quality of a country's business environment?

The ln_BE coefficient is negative and statistically significant in both the European and CEE region models. In the European FE model, a 1% increase in the business environment index is associated with an average decrease in fintech deal size of 1.59%. A similar effect is observed in the CEE RE model, where a 1% increase in the business environment index influences an average decrease of 1.52%. These results suggest that better-developed business environments, which tend to be more stable and mature, do not necessarily attract higher levels of fintech investment.

RQ2: Does the level of education in a country affect the size of fintech deals?

The ln_E variable is not statistically significant in either model. Although the coefficient is negative in both cases, it does not reach conventional levels of significance. This suggests that the level of education, as measured by this index, does not systematically or clearly influence fintech fundraising across the countries examined. It may be that broader innovation capacity or practical skill development (e.g. tech entrepreneurship) is a more relevant factor in explaining capital allocation to fintech ventures than formal education metrics.

RQ3: Does the size of fintech financing deals depend on a country's knowledge workers?

In the European sample, the ln_KW variable is statistically significant and negative. A 1% increase in the knowledge worker index is associated with an average 2.32% decrease in fintech deal size. However, in the CEE RE model, this coefficient becomes statistically insignificant. This finding indicates that, at the broader European level, fintech fundraising tends to be lower in countries with more developed knowledge-intensive labour markets, potentially because these environments are already served by established players or are less open to disruption. In contrast, within the CEE region, the availability of knowledge workers does not appear to significantly influence fintech fundraising outcomes.

RQ4: Does the size of fintech financing deals depend on knowledge impact in the country?

The ln_KI coefficient is consistently negative and statistically significant in both models. In the European FE model, the elasticity is –1.81%, while in the CEE RE model it reaches –3.50%. These results show that countries with higher levels of technological output, research productivity, or innovation diffusion tend to have lower fintech fundraising volumes. One possible explanation is that in highly innovative economies, capital may be diverted toward other technology sectors that are perceived as more scalable or less regulated than financial technology.

RQ5: Do the relationships between innovation factors and fintech fundraising differ between Europe and the CEE region?

In both samples, stronger business environments and higher knowledge-impact scores are associated with smaller fintech deal volumes, but the elasticities are nearly twice as large in the CEE countries. This suggests that when institutional quality or innovation output improves in CEE, the market gaps that once favoured fintechs close more abruptly than in Western Europe and venture capital reallocates toward other, less regulated technology sectors. Consequently, better business conditions and stronger innovation performance do not draw additional fintech fundraising into the region.

These findings are consistent with previous research, suggesting that regions with lower trust in traditional financial services are characterised by greater funding for fintech start-ups, but regions with historically low trust attract less overall fintech investment (Cojoianu et al. 2021). By incorporating sub-indices from the GII, this study suggests that despite improvements in the business environment, education, and knowledge impact, VC fund managers may still favour well-established markets, reflecting broader trust and stability in these environments over purely improved sub-indices.

Table 4. Fixed-effects (FE) and random-effects (RE) panel data model results for the determinants of fintech fundraising in Europe and the CEE region

	Europe (full sample)		CEE region	
	FE	RE	FE	RE
ln_KW	−2.321**	0.469	−2.552*	−1.744
	(1.033)	(1.116)	(1.158)	(1.154)
ln_KI	−1.806***	−1.733***	−3.350**	−3.497***
	(0.645)	(0.614)	(1.266)	(1.168)
ln_BE	−1.592***	−1.373***	−1.663***	−1.519***
	(0.182)	(0.225)	(0.173)	(0.212)
ln_E	−1.057	−0.588	−2.762*	−1.928
	(0.829)	(0.891)	(1.279)	(1.186)
Constant	32.208***	18.007***	44.333***	37.841***
	(4.039)	(4.386)	(3.844)	(4.422)
Hausman p	0.000		0.318	
F test (alpha_i)	28.24***		18.00***	
BP LM p		0.000	.	0.000
Obs.	350	350	110	110
Adj. R^2	0.182		0.290	
Wooldridge F	21.93			
Wooldridge p	0.0000			
Coef L.e	0.247			
rho CEE RE				0.373

Standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: own calculations.

The within R^2 for the European FE model is 0.182, indicating that the model explains approximately 18.2% of the within-country variation in fintech fundraising over time. The CEE RE model achieves a higher adjusted R^2 of 0.290, indicating greater explanatory power within this subsample. In both cases, the Breusch–Pagan Lagrange Multiplier test confirms the presence of significant panel effects ($p = 0.000$), justifying the use of panel models. The F-statistic for fixed effects in Europe is 28.24 ($p < 0.001$), and 18.00 ($p < 0.001$) for the CEE region, indicating strong significance of unobserved country-specific factors in both cases. These diagnostics reveal a substantial share of cross-country heterogeneity that is not captured by the independent variables alone but absorbed through fixed or random effects.

Discussion

Based on the fixed-effects panel models, this study shows significant correlations between the size of fintech sector financing (total deal size) and several factors included in the GII sub-indices. In particular, an increase in the knowledge workers and knowledge impact variables is statistically significantly correlated with a negative change in the total value of fintech transactions. A similar, although slightly weaker, trend was observed for business environment and education variables, while in the CEE subsample, the negative effects of knowledge impact and business environment are even stronger. This suggests that improvements in these areas more rapidly reduce the market space available for fintech solutions in less mature financial systems, which is consistent with the discussion on the multifaceted and system-level nature of factors shaping investments in the fintech sector discussed in the literature (Cojoianu et al. 2021; Turki and Rieg 2023).

These results confirm the complexity and interdisciplinary dimension of the determinants of fintech development, as observed by other scholars (Demirgüç-Kunt and Levine 2018; Demirgüç-Kunt et al. 2020; 2021; Cornelli et al. 2021). Cornelli et al. (2021) point to the key importance of regulatory support, including regulatory sandboxes. However, as our results show, increased knowledge or a better business environment alone does not guarantee a higher total value of investments in fintech. This pattern is particularly visible in the CEE countries, where higher values of both indices are associated with a decline in fundraising almost double that observed in the broader European sample. This may be because investors prefer to invest in markets with proven commercial potential, and not necessarily in sectors that show progressive improvement in innovation sub-indices. Cojoianu et al. (2021) draw a similar conclusion, noting that even in regions with low trust in traditional banking, in the absence of other favourable conditions, the scale of investments in fintech companies remains relatively limited.

Our research also shows that the Investment ("market sophistication") sub-index is not a factor that significantly affects the total value of funds raised by fintechs, a result that holds for both the full European panel and the CEE subsample. This is consistent with earlier observations by Haddad and Hornuf (2019), who observe that the availability of high-risk capital does not always boost fintech funding unless other factors, such as regulations or the general investment climate, also support its development.

The negative effects observed for Knowledge Workers, Knowledge Impact, Business Environment, and Education indicate that enhancements in these domains do not necessarily boost fintech fundraising. One potential explanation is that when early-stage and growth finance is limited or dispersed across a range of investor types, additional innovation capacity is directed towards developed sectors or projects with more apparent commercial prospects. This finding is consistent with the evidence that investors tend to focus on ecosystems with proven scaling potential and stable deal flow (Haddad and Hornuf 2019; Demirgüç-Kunt et al. 2020; Cornelli et al. 2021). Another explanation lies in institutions, where regulatory clarity and coherent governance matter more for entrepreneurial finance than isolated gains in education or knowledge creation (Demirgüç-Kunt and Levine 2018; Cornelli et al. 2021). In CEE markets, which are typically characterised by less developed capital markets and fintech ecosystems, poor coordination between regulation, supervision, and innovation policy raises perceived risk, reduces market depth and absorptive capacity, and deters investor commitments (Cojoianu et al. 2023; Turki and Rieg 2023).

Conclusions

In addressing the identified gaps, limitations, and recommendations, this paper enhances our understanding of the relationship between four GII subindices (Business Environment, Education, Knowledge Workers, Knowledge Impact) and the total value of fintech fundraising across 35 European economies and the CEE region between 2013–2022.

Theoretical contribution and managerial implications

While the conclusions of this study are practical, they also contribute to the existing body of knowledge. Specifically, the estimates indicate that higher scores in Business Environment, Knowledge Workers and Knowledge Impact are negatively associated with total fintech fundraising in Europe, with larger elasticities in the CEE subsample, while Education is statistically insignificant. Thus, improvements in these dimensions are associated with lower, rather than higher, fintech equity flows within the sample period. This insight is especially relevant for governments and funds in CEE, where recent improvements in institutional and innovation indicators have been associated with declines in fintech fundraising rather than increases. This pattern is consistent with previous studies that emphasise the need for an integrated, system-level approach to developing the fintech sector and to innovation finance more broadly (Van Roy and Nepelski 2017; Haddad and Hornuf 2019; Cornelli et al. 2021; World Bank 2022; Cojoianu et al. 2023). Our results nuance this view by showing that an increase in innovation and business climate indexes does not necessarily lead to fintech-specific equity flows.

In addition, the weakness or instability of regulations in certain countries (Kliber et al. 2021), persistent uncertainty in the availability of qualified staff, and shallow domestic venture capital markets can severely hinder the development of the fintech market, even when GII sub-indices improve (Haddad and Hornuf 2019; World Bank 2022). The negative associations observed are consistent with two mechanisms. First, high-innovation environments may experience market saturation and a displacement of capital toward other technology sectors. Second, regulatory clarity and the depth of venture markets appear to matter more for fintech fundraising than

incremental improvements in education or knowledge creation. This is particularly apparent in CEE countries, where dynamic changes in the GII sub-indices do not bring about the expected investment growth, in line with evidence on regulatory barriers, limited early-stage and scale-up finance, and the region's still nascent fintech ecosystem (Van Roy and Nepelski 2017; Kliber et al. 2021; Iwanicz-Drozdowska et al. 2023).

Limitations

A limitation of the analysis is its focus on European countries and the use of annual data spanning 2013 to 2022. Expanding the scope of this study to cover other regions of the world would allow us to ascertain whether the identified relationships are universal or specific to Europe. In particular, including non-European emerging markets could verify whether the stronger substitution effect observed in the CEE countries also arises outside the continent. Moreover, at the time of constructing the dataset, several of the most recent GII indicators were not yet available, which constrained the temporal coverage and precision of some innovation measures. Subsequently, it would be useful to include additional control variables (e.g., interest rates and digitalisation of the financial sector), as well as results obtained from **BIS** (Bank of International Settlements) research (Cornelli et al. 2021), analysing how mergers and acquisitions by large banks and large technology companies (BigTechs) affect fintech investment. This would offer a broader perspective and provide better insights for policymakers, investors, and the fintech sector itself.

Future research

Future research could extend this analysis in several directions. First, incorporating broader economic and sustainability-related aspects would align with recent studies that view fintech and related digital innovations through the lens of sustainable development, sectoral structure, and macro-financial performance (Barua et al. 2025; Golder and Barua 2025). Second, it could focus more explicitly on financing technology transfer from universities and public research institutes, including the role of university spin-offs, technology transfer offices, and public–private partnership schemes. This would build on existing literature on barriers to university technology transfer and entrepreneurial ecosystems (Van Roy and Nepelski 2017; Quiñones et al. 2020; Trinugroho et al. 2021). Third, combining firm- and deal-level data on fintech fundraising with regional indicators of knowledge creation and trust in incumbent financial institutions could reveal the micro-level mechanisms behind the country-level patterns documented in this study (Cojoianu et al. 2023). Finally, qualitative research, such as interviews with investors, fintech founders, and regulators in CEE and Western Europe, could provide further insight into how perceived regulatory risk, human capital constraints, and market structure influence strategic decisions regarding fintech investment and expansion (Ruhland and Wiese 2023; Panday, Nyawo, and Vilakazi 2024).

Appendix

Table A1. Variance Inflation Factors (VIF) for explanatory variables

Variable	VIF	1/VIF
ln_I	2.04	0.49
ln_BE	1.91	0.52
ln_KW	1.68	0.59
ln_E	1.40	0.72
ln_KI	1.09	0.92
Mean VIF	1.62	

Source: own calculations.

References

Al-Assaf, G., Abdel-Halim, M., Shehadeh, M. (2025), *The macroeconomic drivers of fintech development in emerging markets: an empirical investigation*, "Discover Sustainability", 6 (1), 863, https://doi.org/10.1007/s43621-025-01597-9

Al-Mannaei, M., Al-Jayyousi, O., Mahmood, A., Dornberger, U., Al-Jayousi, N. (2023), *Evaluating innovation performance for financial technology within the national innovation system: A case study of the Kingdom of Bahrain*, "Entrepreneurial Business and Economics Review", 11 (2), pp. 185–199, https://doi.org/10.15678/EBER.2023.110210

Alaassar, A., Mention, A.L., Aas, T.H. (2021), *Exploring a new incubation model for FinTechs: Regulatory sandboxes*, "Technovation", 103, https://doi.org/10.1016/j.technovation.2021.102237

Alaassar, A., Mention, A.-L., Aas, T.H. (2023), *Facilitating innovation in FinTech: A review and research agenda*, "Review of Managerial Science", 17 (1), pp. 33–66, https://doi.org/10.1007/s11846-022-00531-x

Ashta, A., Herrmann, H. (2021), *Artificial intelligence and fintech: An overview of opportunities and risks for banking, investments, and microfinance*, "Strategic Change", 30 (3), pp. 211–222, https://doi.org/10.1002/jsc.2404

Atomico (2023), *State of European Tech 2023. Europe's Definitive Tech Report*, London, https://www.investeurope.eu/media/7424/atomico-state-of-european-tech-report-2023.pdf (accessed: 5.04.2025).

Audretsch, D.B., Keilbach, M. (2007), *The Theory of Knowledge Spillover Entrepreneurship*, "Journal of Management Studies", 44 (7), pp. 1242–1254, https://doi.org/10.1111/j.1467-6486.2007.00722.x

Baig, M.H., Xu, J., Shahzad, F., Ali, R. (2025), *Revealing the potential of FinTech innovation through knowledge assets: a study of firm financial performance*, "International Journal of Innovation Science", 17 (3), pp. 650–682, https://doi.org/10.1108/IJIS-09-2023-0204

Barney, J.B. (2001), *Is the Resource-Based "View" a Useful Perspective for Strategic Management Research? Yes'*, "The Academy of Management Review", 26 (1), pp. 41–56, https://doi.org/10.2307/259393

Barua, S., Golder, U., Chowdhury, R.S., Sharmeen, K. (2025), *Implications of NFT as a sustainable fintech innovation for sustainable development and entrepreneurship*, "Sustainable Technology and Entrepreneurship", 4 (2), 100099, https://doi.org/10.1016/j.stae.2025.100099

Bhutto, S.A., Jamal, Y., Ullah, S. (2023), *FinTech adoption, HR competency potential, service innovation and firm growth in banking sector*, "Heliyon", 9 (3), e13967, https://doi.org/10.1016/j.heliyon.2023.e13967

Bömer, M., Schwienbacher, A. (2018), *Resource-Based Perspective of VC Investments in Fintech*, "SSRN Electronic Journal", https://doi.org/10.2139/ssrn.3312793

CB Insights (2022), *State of Fintech Global | Q2 2022*, New York.

CB Insights (2024), *State of Venture Global | Q1 2024*, New York.

Claessens, S., Frost, J., Turner, G., Zhu, F. (2018), *Fintech Credit Markets Around the World: Size, Drivers and Policy Issues*, "BIS Quarterly Review", Bank for International Settlements, Basel.

Cojoianu, T.F., Clark, G.L., Hoepner, A.G.F., Pažitka, V., Wójcik, D. (2021), *Fin vs. tech: are trust and knowledge creation key ingredients in fintech start-up emergence and financing?*, "Small Business Economics", 57 (4), pp. 1715–1731, https://doi.org/10.1007/s11187-020-00367-3

Cojoianu, T.F., Hoepner, A.G.F., Schneider, F.I., Urban, M., Vu, A., Wójcik, D. (2023), *The city never sleeps: but when will investment banks wake up to the climate crisis?*, "Regional Studies", 57 (2), pp. 268–286, https://doi.org/10.1080/00343404.2021.1995601

Cornelli, G., Doerr, S., Franco, L., Frost, J. (2021), *Funding for Fintechs: Patterns and Drivers*, "BIS Quarterly Review", Bank for International Settlements, Basel.

Cornelli, G., Doerr, S., Gambacorta, L., Merrouche, O. (2024), *Regulatory Sandboxes and Fintech Funding: Evidence from the UK*, "Review of Finance", 28 (1), pp. 203–233, https://doi.org/10.1093/rof/rfad017

Cumming, D., Johan, S., Reardon, R. (2023), *Global fintech trends and their impact on international business: a review*, "Multinational Business Review", 31 (3), pp. 413–436, https://doi.org/10.1108/MBR-05-2023-0077

Cumming, D.J., Schwienbacher, A. (2018), *Fintech venture capital*, "Corporate Governance: An International Review", 26 (5), pp. 374–389, https://doi.org/10.1111/corg.12256

Da Rin, M., Penas, M.F. (2019), *Venture Capital and Innovation Strategies*, "Journal of Business Venturing", 34 (1), pp. 1–22.

Dańska-Borsiak, B. (2011), *Dynamiczne modele panelowe w badaniach ekonomicznych*, Wydawnictwo Uniwersytetu Łódzkiego, Łódź, https://doi.org/10.18778/7525-549-2

Demirgüç-Kunt, A., Klapper, L., Singer, D., Ansar, S. (2021), *Financial Inclusion, Digital Payments, and Resilience in the Age of COVID-19*, World Bank, Washington.

Demirgüç-Kunt, A., Klapper, L., Singer, D., Ansar, S., Hess, J. (2020), *The Global Findex Database 2017: Measuring Financial Inclusion and Opportunities to Expand Access to and Use of Financial Services*, "World Bank Economic Review", 34 (Supplement_1), pp. S2–S8, https://doi.org/10.1093/wber/lhz013

Demirgüç-Kunt, A., Levine, R. (2018), *Finance and Growth*, Edward Elgar Publishing, Cheltenham, https://doi.org/10.4337/9781785367434

Direction générale du Trésor (2024), *The Tibi Initiative: Phase-2 and Perspectives*, Ministère de l'Économie, Paris, https://www.tresor.economie.gouv.fr/Articles/2024/05/15/the-tibi-initiative-phase-2-and-perspectives-1 (accessed: 5.04.2025).

Direction générale du Trésor (2025), *TIBI initiative: a target raised to €15 billion*, Ministère de l'Économie, Paris, https://www.tresor.economie.gouv.fr/Articles/2025/09/16/tiibi-initiative-a-target-raised-to-15-billion (acessed: 5.04.2025).

Drukker, D.M. (2003), *Testing for Serial Correlation in Linear Panel-data Models*, "The Stata Journal: Promoting Communications on Statistics and Stata", 3 (2), pp. 168–177, https://doi.org/10.1177/1536867X0300300206

Edquist, C. (2009), *Systems of Innovation: Perspectives and Challenges*, [in:] J. Fagerberg, D.C. Mowery (eds.), *The Oxford Handbook of Innovation*, Oxford University Press, Oxford, pp. 181–208, https://doi.org/10.1093/oxfordhb/9780199286805.003.0007

Etzkowitz, H., Leydesdorff, L. (2000), *The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations*, "Research Policy", 29 (2), pp. 109–123, https://doi.org/10.1016/S0048-7333(99)00055-4

European Central Bank (2023), *Financial Stability Review*, Frankfurt am Main, https://www.ecb.europa.eu/pub/pdf/fsr/ecb.fsr202305~65f8cb74d7.en.pdf (accessed: 5.04.2025).

Freeman, C. (1995), *The "National System of Innovation" in historical perspective*, "Cambridge Journal of Economics", 19 (1), pp. 5–24, https://doi.org/10.1093/oxfordjournals.cje.a035309

Golder, U., Barua, S. (2025), *The dynamic linkage between fintech venture capital funding, bank credit flows, and equity market movement: evidence from a global perspective*, "Financial Innovation", 11 (1), 120, https://doi.org/10.1186/s40854-025-00791-y

Golder, U., Barua, S., Abedin, M.Z., Adu, D.A., Ren, B. (2025), *Determinants of FinTech Equity Funding Flows: Evidence From a Global Perspective*, "International Journal of Finance & Economics", 30 (4), pp. 3681–3708, https://doi.org/10.1002/ijfe.3086

Gomber, P., Koch, J.A., Siering, M. (2017), *Digital Finance and FinTech: current research and future research directions*, "Journal of Business Economics", 87 (5), pp. 537–580, https://doi.org/10.1007/s11573-017-0852-x

Gompers, P., Lerner, J. (1996), *The Use of Covenants: An Empirical Analysis of Venture Partnership Agreements*, "Journal of Law and Economics", 39 (2), pp. 463–498, https://doi.org/10.1086/467356

Haddad, C., Hornuf, L. (2019), *The emergence of the global fintech market: economic and technological determinants*, "Small Business Economics", 53 (1), pp. 81–105, https://doi.org/10.1007/s11187-018-9991-x

Hall, P.A., Soskice, D. (eds.) (2001), *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*, Oxford University Press, Oxford, https://doi.org/10.1093/0199247757.001.0001

Harasim, J. (2021), *FinTechs, BigTechs and structural changes in capital markets*, [in:] A. Marszk, E. Lechman (eds.), *The Digitalization of Financial Markets. The Socioeconomic Impact of Financial Technologies*, Routledge, London, pp. 80–100, https://doi.org/10.4324/9781003095354-5

Herck Giaquinto, L., Bruscato Bortoluzzo, A. (2020), *Angel investors, seed-stage investors and founders influence on FinTech funding: an emerging market context*, "Macroeconomics and Finance in Emerging Market Economies", 13 (3), pp. 276–294, https://doi.org/10.1080/17520843.2020.1737169

Ivanova, I., Strand, Ø., Kushnir, D., Leydesdorff, L. (2017), *Economic and technological complexity: A model study of indicators of knowledge-based innovation systems*, "Technological Forecasting and Social Change", 120, pp. 77–89, https://doi.org/10.1016/j.techfore.2017.04.007

Iwanicz-Drozdowska, M., Cichowicz, E., Cicirko, M., Kawiński, M., Nowak, A.K. (2023), *New technologies in the financial industry: case of Poland*, "Economics and Business Review", 9 (3), https://doi.org/10.18559/ebr.2023.3.926

Jain, R., Prajapati, D., Dangi, A. (2023), *Transforming the Financial Sector: A Review of Recent Advancements in FinTech*, "International Journal for Research Trends and Innovation", 8 (2).

Jeng, L.A., Wells, P.C. (2000), *The determinants of venture capital funding: evidence across countries*, "Journal of Corporate Finance", 6 (3), pp. 241–289, https://doi.org/10.1016/S0929-1199(00)00003-1

Kamuangu, P. (2024), *Advancements of AI and Machine Learning in FinTech Industry (2016–2020)*, "Journal of Economics, Finance and Accounting Studies", 6 (1), pp. 23–31, https://doi.org/10.32996/jefas.2024.6.1.3

Kassner, A.J. (2024), *Factors influencing investment into PropTech and FinTech – only new rules or a new game?*, "Journal of European Real Estate Research", 17 (3), pp. 395–411, https://doi.org/10.1108/JERER-04-2023-0011

Khlystova, O., Kalyuzhnova, Y., Belitski, M. (2022), *Towards the regional aspects of institutional trust and entrepreneurial ecosystems*, "International Journal of Entrepreneurial Behavior & Research", https://doi.org/10.1108/IJEBR-02-2022-0108

Kliber, A., Będowska-Sójka, B., Rutkowska, A., Świerczyńska, K. (2021), *Triggers and Obstacles to the Development of the FinTech Sector in Poland*, "Risks", 9 (2), 30, https://doi.org/10.3390/risks9020030

Kolokas, D., Vanacker, T., Veredas, D., Zahra, S.A. (2022), *Venture Capital, Credit, and FinTech Start-Up Formation: A Cross-Country Study*, "Entrepreneurship Theory and Practice", 46 (5), pp. 1198–1230, https://doi.org/10.1177/1042258720972652

Kumari, A., Chitra Devi, N. (2022), *The Impact of FinTech and Blockchain Technologies on Banking and Financial Services*, "Technology Innovation Management Review", 12 (1–2), https://doi.org/10.22215/timreview/1481

La Porta, R., Shleifer, A. (2008), *The Unofficial Economy and Economic Development*, "NBER Working Paper", 14520, National Bureau of Economic Research, Cambridge, https://doi.org/10.3386/w14520

Laidroo, L., Avarmaa, M. (2020), *The role of location in FinTech formation*, "Entrepreneurship and Regional Development", 32 (7–8), pp. 555–572, https://doi.org/10.1080/08985626.2019.1675777

Lundvall, B.-Å. (2007), *National Innovation Systems – Analytical Concept and Development Tool*, "Industry & Innovation", 14 (1), pp. 95–119, https://doi.org/10.1080/13662710601130863

Maple, C., Szpruch, L., Epiphaniou, G., Staykova, K., Singh, S., Penwarden, W., Wen, Y., Wang, Z., Hariharan, J., Avramovic, P. (2023), *The AI Revolution: Opportunities and Challenges for the Finance Sector*, https://doi.org/10.48550/arXiv.2308.16538

Milian, E.Z., Spinola, M.D.M., Carvalho, M.M.D. (2019), *Fintechs: A literature review and research agenda*, "Electronic Commerce Research and Applications", 34, 100833, https://doi.org/10.1016/j.elerap.2019.100833

Moccia, S., Passerini, K., Tomic, I. (2018), *Fintech: Challenges, Drivers, and Future Opportunities*, "Cutter Business Technology Journal", 31 (11–12), pp. 6–11.

Natarajan, H. (2020), *Editorial: FinTech's impact on payments – Part 1*, "Journal of Payments Strategy and Systems", 14 (4), pp. 312–314, https://doi.org/10.69554/QFZY7695

Nelson, R.R. (ed.) (1993), *National Innovation Systems: A Comparative Analysis*, Oxford University Press, New York.

Niewinska, K. (2023), *FinTech Sector: A Review of Research Trends for the Period of 2015–2022*, "Scientific Papers of Silesian University of Technology. Organization & Management (Zeszyty Naukowe Politechniki Śląskiej. Seria Organizacji i Zarządzanie)", 181, pp. 387–412, https://doi.org/10.29119/1641-3466.2023.181.26

North, D.C. (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge University Press, Cambridge, https://doi.org/10.1017/CBO9780511808678

OECD (2002), *Dynamising National Innovation Systems*, OECD Publishing, Paris, https://www.oecd.org/content/dam/oecd/en/publications/reports/2002/05/dynamising-national-innovation-systems_g1gh29d9/9789264194465-en.pdf (accessed: 5.04.2025).

Panday, L., Nyawo, J.C., Vilakazi, M.B.F. (2024), *Financial technology in a South African banking institution to achieve strategic sustainability*, "South African Journal of Business Management", 55 (1), a4587, https://doi.org/10.4102/sajbm.v55i1.4587

Priyanka, G. (2024), *Benefits and Risks of Generative AI in FinTech*, "Journal of Scientific and Engineering Research", 11 (5), pp. 267–275.

Quiñones, R.S., Caladcad, J.A.A., Himang, C.M., Quiñones, H.G., Castro, C.J., Caballes, S.A.A., Abellana, D.P.M., Jabilles, E.M.Y., Ocampo, L.A. (2020), *Using Delphi and fuzzy DEMATEL for analyzing the intertwined relationships of the barriers of university technology transfer: Evidence from a developing economy*, "International Journal of Innovation Studies", 4 (3), pp. 85–104, https://doi.org/10.1016/j.ijis.2020.07.002

Ruhland, P., Wiese, F. (2023), *FinTechs and the financial industry: partnerships for success*, "Journal of Business Strategy", 44 (4), pp. 228–237, https://doi.org/10.1108/JBS-12-2021-0196

Ryu, H.-S. (2025), *From Innovation to Use: Configurational Pathways to High Fintech Use Across User Groups*, "Sustainability", 17 (17), 7762, https://doi.org/10.3390/su17177762

Saiyed, A. (2025), *AI-Driven Innovations in Fintech: Applications, Challenges, and Future Trends*, "International Journal of Electrical and Computer Engineering Research", 5 (1), pp. 8–15, https://doi.org/10.53375/ijecer.2025.437

Spigel, B. (2017), *The Relational Organization of Entrepreneurial Ecosystems*, "Entrepreneurship Theory and Practice", 41 (1), pp. 49–72, https://doi.org/10.1111/etap.12167

Tello-Gamarra, J., Campos-Teixeira, D., Andrade Longaray, A., Reis, J., Hernani-Merino, M. (2022), *Fintechs and Institutions: A Systematic Literature Review and Future Research Agenda*, "Journal of Theoretical and Applied Electronic Commerce Research", 17 (2), pp. 722–750, https://doi.org/10.3390/jtaer17020038

Tödtling, F., Trippl, M. (2005), *One size fits all?: Towards a differentiated regional innovation policy approach*, "Research Policy", 34 (8), pp. 1203–1219, https://doi.org/10.1016/j.respol.2005.01.018

Trinugroho, I., Santoso, W., Irawanto, R., Pamungkas, P. (2021), *Is spin-off policy an effective way to improve performance of Islamic banks? Evidence from Indonesia*, "Research in International Business and Finance", 56, 101352, https://doi.org/10.1016/j.ribaf.2020.101352

Turki, A., Rieg, R. (2023), *On performance drivers of European Fintechs around venture capital: exploring the role of founders' experience*, "Review of Accounting and Finance", 22 (5), pp. 682–699, https://doi.org/10.1108/RAF-05-2023-0153

Van Roy, V., Nepelski, D. (2017), *Determinants of High-Tech Entrepreneurship in Europe*, Joint Research Centre, Publications Office of the European Union, Luxembourg.

Vijayagopal, P., Jain, B., Viswanathan, S.A. (2024), *Regulations and Fintech: A Comparative Study of the Developed and Developing Countries*, "Journal of Risk and Financial Management", 17 (8), 324, https://doi.org/10.3390/jrfm17080324

Wernerfelt, B. (1984), *A resource-based view of the firm*, "Strategic Management Journal", 5 (2), pp. 171–180, https://doi.org/10.1002/smj.4250050207

World Bank (2022), *Global Patterns of Fintech Activity and Enabling Factors: Fintech and the Future of Finance Flagship Technical Note*, Washington, https://documents1.worldbank.org/curated/en/099735504212234006/pdf/P1730060695b370090908c0bf80ed27eba6.pdf (accessed: 5.04.2025).

World Economic Forum (2025), *Artificial Intelligence in Financial Services*, Geneva, https://reports.weforum.org/docs/WEF_Artificial_Intelligence_in_Financial_Services_2025.pdf (accessed: 5.04.2025).

World Intellectual Property Organization (2023a), *Global Innovation Index 2023: Innovation in the face of uncertainty*, Geneva, https://www.wipo.int/edocs/pubdocs/en/wipo-pub-2000-2023-en-main-report-global-innovation-index-2023-16th-edition.pdf (accessed: 5.04.2025).

World Intellectual Property Organization (2023b), *World Intellectual Property Indicators 2023*, Geneva, https://www.wipo.int/edocs/pubdocs/en/wipo-pub-941-2023-en-world-intellectual-property-indicators-2023.pdf (accessed: 5.04.2025).

Zarrouk, H., Ghak, T.E., Bakhouche, A. (2021), *Exploring Economic and Technological Determinants of Fintech Startups' Success and Growth in the United Arab Emirates*, "Journal of Open Innovation: Technology, Market, and Complexity", 7 (1), 50, https://doi.org/10.3390/joitmc7010050

Zhang, B.Z., Ashta, A., Barton, M.E. (2021), *Do FinTech and financial incumbents have different experiences and perspectives on the adoption of artificial intelligence?*, "Strategic Change", 30 (3), pp. 223–234, https://doi.org/10.1002/jsc.2405

Determinanty pozyskiwania finansowania fintechów w Europie

W artykule przeanalizowano wpływ pięciu subindeksów Global Innovation Index (GII) na łączną wartość transakcji finansujących start-upy w sektorze fintech w 35 krajach Europy, w tym w 11 krajach w regionie Europy Środkowo-Wschodniej (CEE). Zastosowano regresję panelową opartą na rocznych danych z lat 2013–2022. W analizie całej próby, czyli 35 krajów w Europie, przeprowadzono estymację przy użyciu modeli z efektami stałymi, natomiast w wyodrębnionej grupie państw CEE wybrano model z efektami losowymi. Zmienną zależną była łączna kwota finansowania fintechów, a zmiennymi objaśniającymi pięć subindeksów GII. Współczynniki dla zmiennych dotyczących pracowników wiedzy, wpływu wiedzy oraz otoczenia biznesowego okazały się ujemne i statystycznie istotne; efekt ten był jeszcze silniejszy w podpróbie CEE. Wyniki sugerują, że poprawa analizowanych czynników nie musi przekładać się na większe finansowanie rynkowe start-upów. Badanie wzbogacą literaturę dotyczącą pozyskiwania finansowania przedsiębiorstw, w szczególności sektora fintech, wskazując, że wzrost wartości badanych subindeksów GII nie gwarantuje wyższych poziomów inwestycji w młode przedsiębiorstwa. Ograniczeniem jest europejski zakres danych oraz okres obejmujący jedynie lata 2013–2022. Dalsze prace badawcze mogą rozszerzyć zasięg geograficzny lub uwzględnić dodatkowe zmienne.

Słowa kluczowe: fintech, pozyskiwanie kapitału, fundusze venture capital, inwestycje fintech, ekosystem innowacji

Comparative Economic Research. Central and Eastern Europe
Volume 29 Number 1, 2026
https://doi.org/10.18778/1508-2008.29.08

Youth Unemployment in the Countries of Central and Eastern Europe. Is Okun's Law Applicable?

Eugeniusz Kwiatkowski https://orcid.org/0000-0001-9030-1664
Prof., Warsaw University of Technology, College of Economics and Social Sciences, Plock, Poland,
e-mail: eugeniusz.kwiatkowski@pw.edu.pl

Agnieszka Krzętowska https://orcid.org/0000-0001-9518-2481
Ph.D., Warsaw University of Technology, College of Economics and Social Sciences, Plock, Poland,
e-mail: agnieszka.krzetowska@pw.edu.pl

Abstract

This article investigates the empirical validity of Okun's law regarding youth unemployment in 11 Central and Eastern European countries between 2000 and 2023. Using panel data disaggregated by age cohorts and gender, the study employs robust linear regression models (RLM) with Huber loss functions and two-way fixed effects models (TWFE). Focusing primarily on the 15–24 age cohort, the results confirm a statistically significant, negative relationship between economic growth and youth unemployment, with considerable heterogeneity across countries and gender groups. While Okun's law holds strongly in the Baltic states and Poland, the relationship is notably weaker in Hungary and Romania. The study also shows that higher shares of temporary employment and higher Employment Protection Legislation (EPL) indices for regular employment reduce the sensitivity of youth unemployment to changes in GDP, whereas higher youth enrolment rates and higher EPL indices for temporary employment increase this sensitivity.

Keywords: youth unemployment, Okun's law, Central and Eastern Europe, panel regression
JEL: C23, E24, J21, J64, P52

Funding information: Warsaw University of Technology, College of Economics and Social Sciences, Plock, Poland.
The percentage share of the Authors in the preparation of the work is: E.K. – 50.00%, A.K. – 50.00%.
Declaration regarding the use of GAI tools: Not used.
Conflicts of interests: None.
Ethical considerations: The Authors assure of no violations of publication ethics and take full responsibility for the content of the publication.
Received: 16.07.2025. Verified: 9.10.2025. Accepted: 3.02.2026

Introduction

Labour markets in Central and Eastern European (CEE) countries have undergone a series of transformations in the 21st century. Although unemployment rates have generally trended downward over the past two decades, relatively high levels persist in specific segments of the labour force. In many CEE countries, the unemployment rate among youth aged 15–24 remains significantly higher than that of the total population.

In the economic literature, several factors have been identified that contribute to this situation. First of all, young people entering the labour market may have qualifications that are not well matched to employers' requirements, which results in quick job dismissals (Blanchard 1997). Secondly, the relatively high mobility of young people contributes to more frequent job changes, which can sometimes lead to unemployment (O'Reilly et al. 2015). Thirdly, in the event of an economic downturn, employers are more likely to lay off young people than older ones, as the costs of employment adjustments are lower for young people (Kwiatkowski and Włodarczyk 2014).

The scale of unemployment, including youth unemployment, depends on various economic, social, demographic, and institutional factors. The literature on this topic is vast, particularly on macroeconomic determinants. Economic theory highlights the crucial role of the level and change in economic output. The importance of output dynamics for shaping unemployment, including youth unemployment, was emphasised in Keynes' theory. He argued that increasing aggregate demand for goods boosts production volumes and employment levels, ultimately reducing unemployment. Conversely, a fall in aggregate demand reduces production and increases unemployment (Keynes 1985:51). This idea was later extended by Okun, who estimated a statistical relationship between changes in unemployment rates and the output growth rate in the U.S. His findings suggested that each additional percentage point (p.p.) of unemployment above 4% was associated with a three p.p. reduction in real GNP growth (Okun 1962). This relationship is known in the economic literature as Okun's Law.

This article analyses the phenomenon of youth unemployment in CEE countries over the period 2000–2023. The countries included in the analysis are Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. The study aims to illustrate the differences in youth unemployment rates between these countries and determine the impact of GDP growth on the development of this phenomenon, thus determining whether Okun's Law applies to youth unemployment. We attempt to answer the question of whether this relationship, formulated in the 1960s, is confirmed for youth unemployment in the 21st century.

This article contributes to the empirical literature examining Okun's law in CEE countries, taking into account the development of this law among youth and other age cohorts, as well as the roles of factors such as temporary employment, employment protection legislation, and the enrolment rate.

The article is structured as follows. Section 2 reviews studies on unemployment in CEE countries, with particular attention paid to youth unemployment. Section 3 outlines the data sources and the research methods employed. Section 4 presents trends in youth unemployment and its determinants

in the countries under study. Section 5 introduces econometric models, indicating the role of GDP changes and other factors in shaping youth unemployment and unemployment in other age cohorts. The results of the analysis are discussed in Section 6, while Section 7 presents the main conclusions drawn from the analysis.

Literature Review

Labour market analyses in CEE countries have been conducted by researchers from the region and Western countries, who turned their attention to this group of economies as far back as the early stages of the systemic transformation.

The unemployment problem in CEE countries in the 1990s was addressed by Nesporova and Cazes (Nesporova 2002; Cazes and Nesporova 2004). Observing the persistently high unemployment rate in the transformation countries, they identified the causes of this situation and its countermeasures. They rejected the view of neoliberal economists, who saw the cause of this situation as the excessive rigidity of labour markets. Based on collected data and information, they demonstrated that in the 1990s, labour markets in the transformation countries became more flexible, as evidenced by the growing share of temporary employment and rising rates of flows of people on the labour market, as well as decreasing indices of employment protection legislation in many countries. They further claimed that high persistent unemployment results from the model adopted in CEE countries, where the responsibility for supporting people laid off from work was transferred from enterprises to public institutions dealing with job placement, active labour market programs, and financial support for the unemployed. This model should increase both the flexibility of adjustments in the labour market and the effectiveness of sectoral allocation of the labour force and overall labour productivity. However, the effectiveness of financial assistance to the unemployed and the speed of finding a new job depend on the quality and efficiency of public institutions, which do not always perform their tasks properly.

Labour market issues in transitional economies were also addressed by Guzikowski (2016), who focused on the interactions between labour market institutions in CEE countries. One chapter, in particular, presents findings and tendencies relevant to this study regarding unemployment and its determinants in the region. Based on statistical data from 1994–2011, he revealed several key patterns in transitional countries: adverse effects of migration on domestic labour supply, low labour force participation among working-age populations (especially youth), relatively high youth unemployment rates, a large share of long-term unemployment, unfavourable changes in the educational structure of the unemployed, relatively low spending on active labour market policies, and relatively high though declining employment protection legislation (EPL) indices.

Gozgor (2013) examined the causes of high unemployment in CEE countries by testing whether labor markets follow the NAIRU (Non-Accelerating Inflation Rate of Unemployment) hypothesis – where unemployment rates are cyclical deviations from the natural rate of unemployment – or the unemployment hysteresis hypothesis, which suggests that adverse shocks lead to permanently higher unemployment levels. By analyzing monthly data from 1998 to 2012, the author concluded

that unemployment persistence is indeed present in CEE countries, supporting the hysteresis hypothesis.

Hutengs and Stadtmann (2013) calculated age-specific Okun coefficients for some CEE countries and EU15 countries, revealing that economic growth has a more pronounced effect on youth unemployment (ages 15–24) than on the elderly population. Similarly, Zanin (2014) analyzed OECD data for 1998–2012 to show that Okun coefficients vary by age and gender, with the youngest generations proving most vulnerable to business cycle fluctuations. His study confirmed that economic growth strongly reduces youth unemployment.

Using 1992–2014 panel data for Eastern European countries, Soylu, Çakmak, and Okur (2018) established the validity of Okun's law, demonstrating that economic growth negatively affects unemployment. This relationship was further explored by Butkus and Seputiene (2019), who applied Okun's law to 28 EU member countries, for the period 2000–2018. They found that youth unemployment is more sensitive to changes in economic growth than total unemployment, and emphasised that youth cohorts are notably more sensitive to adverse output shocks than to positive ones.

Regarding the Polish economy, Bartosik (2020) verified Okun's law and examined the impact of temporary employment on this relationship using data from 1996–2018. Through various OLS regression models, he established a negative link between changes in GDP and the unemployment rate, with unemployment sensitivity to production changes increasing over the period – a trend directly associated with the rise in temporary employment.

Gajderowicz et al. (2014) investigated the sensitivity of unemployment rates to changes in GDP in Polish voivodeships using annual average data from 1995 to 2011. These estimates were based on two models: model 1 relied on changes in unemployment rates and GDP growth rates, while model 2 known as the gap model was based on deviations of these variables from their long-term values. Estimates in the model based on differences were around –0.4, while in the gap model, they were slightly higher, at approximately –0.6 and –0.7.

Dunsch (2016) performed a comparative analysis of unemployment in Poland and Germany, focusing on whether youth unemployment is more sensitive to economic fluctuations than adult unemployment. She estimated Okun's coefficients across five different age groups, using a difference model and data from 1992 to 2014. The results confirmed that youth unemployment is more sensitive to economic fluctuations than adult unemployment, although the differences were smaller in Germany than in Poland. Moreover, the sensitivity of youth unemployment to changes in the economic cycle has proven to be higher in Poland than in Germany. To explain these differences, Dunsch attributed them to variations in employment protection legislation, minimum wages, sectoral employment structures, and the education systems (Dunsch 2016).

Unemployment's sensitivity to GDP changes has been analysed many times in the literature, including in CEE countries (Hutengs and Stadtman 2013; Soylu, Çakmak, and Okur 2018). However, only Hutengs and Stadtman utilized age-cohort analysis to isolate the specific vulnerabilities of young workers. While most models relied solely on GDP growth rates to explain

changes in unemployment, only Bartosik (2020) identified temporary employment as a key driver of this sensitivity.

This article contributes to the literature by combining these approaches: we conduct a multi-cohort sensitivity analysis to assess sensitivity in the youth population while simultaneously evaluating the role of temporary employment, enrolment, and employment protection legislation in moderating these effects.

Data and Methodology

The empirical study analyzes 11 CEE countries from 2000–2023 using annual statistical data from the OECD and Eurostat. The dataset comprises unemployment rates by age cohort, GDP growth rates, and structural variables including GDP *per capita,* the share of temporary employment, EPL indices, and school enrolment rates in the 15–24 age group. The unemployment data are structured as a cohort–time panel, where cross-sectional units are age cohorts disaggregated by gender, and the time dimension is the calendar year. For the eight OECD countries (Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia), the analysis uses six age cohorts (15–24, 25–34, 35–44, 45–54, 55–64, and 65–74), disaggregated by gender (OECD Database 2025). For the non-OECD countries (Bulgaria, Croatia, and Romania), data include four simplified cohorts (15–24, 15–29, 25–54, and 55–74) for the period 2009–2023 (Eurostat Database 2025).

The study was conducted in two stages. The first stage involved an analysis of stylised empirical facts to identify the heterogeneity of youth unemployment and its structural and cyclical context across the examined countries. This phase employed a descriptive, exploratory approach based on panel data, without using regression models. Comparative analyses, rankings, and data visualisations were applied.

In the second stage, three types of econometric models were applied to describe the relationship between the change in the unemployment rate (ΔU) and the annual GDP growth rate (ΔY):

- robust linear model (RLM),
- two-way fixed effects panel model (TWFE),
- extended interactive TWFE model with structural and institutional factors.

The robust linear model (RLM) was based on the following regression function:

$$\Delta U_{ikt} = \alpha + \sum_{k} \gamma_k \cdot (\Delta Y_{it} \cdot D_k) + \varepsilon_{ikt}, \tag{1}$$

where:
ΔU_{ikt} – annual change in unemployment rate for cohort k in year t, country i, defined as the year-to-year difference for the given cohort and gender (in p.p.),
D_k – dummy variable for cohort k,
γ_k– Okun's coefficient for cohort k (elasticity of unemployment in relation to GDP),
ΔY_{it} – annual GDP growth rate (in %),
α – intercept,

ε_{ikt} – error term.

The estimation was conducted using the robust model with the Huber loss function (Huber 1964; Verardi and Croux 2009), which does not require assumptions of homoskedasticity or normality of residuals. To improve the precision of inference, a bootstrap procedure with 400 replications was applied (Efron and Tibshirani 1994).

To improve the reliability of the results obtained from the RLM model, panel models with two-way fixed effects (TWFE) were also estimated, with the following regression function:

$$\Delta U_{ikt} = \propto_i + \tau_t + \gamma \Delta Y_{it} + \varepsilon_{ikt}, \tag{2}$$

where:
ΔU_{ikt} – annual change in the unemployment rate in cohort k (in p.p.),
ΔY_{it}– annual change in real GDP (in %),
α_i – country fixed effect,
τ_i – year fixed effects,
γ – Okun's coefficient,
ε_{ikt} – error term.

Standard errors were clustered by country (Arellano 1987) to ensure robustness to heteroskedasticity and within-unit autocorrelation. To verify gender and spatial differences, Wald tests were conducted.

Finally, models were estimated for three cyclical periods: pre-global financial crisis (GFC) (≤ 2008), post-GFC (2009–2019), and post-COVID-19 pandemic (≥ 2020). To account for structural and institutional labour market factors, the baseline TWFE model was extended with interaction variables:

$$\Delta U_{it} = \alpha_i + \tau_t + \beta_1 \Delta Y_{it} + \beta_2 (\Delta \mathrm{v} Y_{it} \cdot Z_{it}) + \varepsilon_{it}, \tag{3}$$

where:
ΔU_{it} – annual change in the unemployment rate in the 15–24 age cohort (in p.p.),
Z_{it} – interactive variable,
β_1 – Okun's coefficient at the mean level of Z_{it},
β_2 – modifier of Okun's coefficient (change in the strength of the $\Delta Y \rightarrow \Delta U$ relationship depending on the level of Z).

Interactive variables were mean-centred to reduce multicollinearity and allow interpretation of β_1 as the effect at the typical level of the variable. Model estimations were performed in R (R Core Team 2025) using RStudio (Croissant and Millo 2008).

Stylized Facts

The analysis examined labour markets in 11 CEE countries that transitioned from centrally planned to market economies during the 1990s. While all 11 countries are currently European Union members, their institutional frameworks varied: Estonia, Lithuania, Latvia, Slovakia,

and Slovenia joined both the eurozone and the OECD, while Czechia, Hungary, and Poland became OECD members but remain outside the eurozone. The remaining countries Bulgaria, Croatia, and Romania maintained independent currencies and were not OECD members during the study period.

These CEE countries fall into the category of middle-income economies, with GDP *per capita* levels in 2023 ranging between €7,900 (Bulgaria) and €22,100 (Slovenia). Economic development was accompanied by significant structural transformations, consistent with the three-sector theory of the economy. The relative importance of the agricultural sector decreased, while the relative importance of the service sector increased.

Figure 1 illustrates the trends in total and youth unemployment rates (age 15–24) from 2000 to 2023. Several conclusions emerge from these charts.

1. Youth unemployment rates remained significantly higher than total unemployment rates across all examined countries.
2. While the dynamics of both indicators followed similar patterns, their trajectories varied across subperiods. A substantial decline occurred between 2000 and 2008 (excluding Hungary and Romania), followed by an increase from 2009–2013 in all countries. A significant secondary decline was observed from 2014 to 2019, with a brief COVID-19-related spike in 2020. In the final years of the study, rates stabilized at low levels, except in Croatia, Estonia, Romania, and Slovakia, where youth unemployment approached 20%.
3. While both indicators exhibited considerable volatility over the entire period, fluctuations were significantly more pronounced in youth unemployment than in total unemployment.

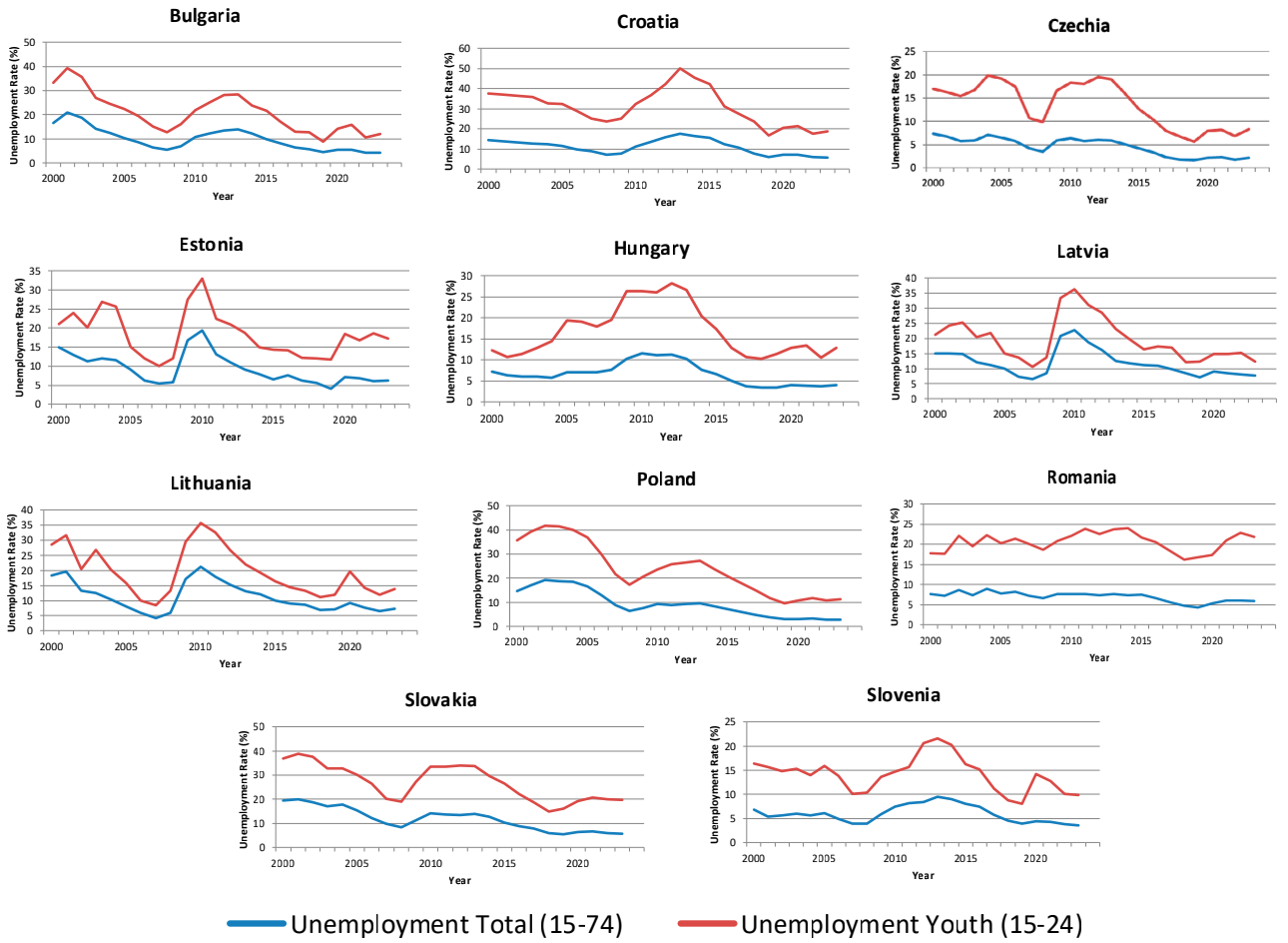


Figure 1. Trends in youth and total unemployment rates in CEE countries, 2000–2023 (in %)
Source: own study based on data from Eurostat Database 2025.

Table 1 presents youth unemployment rates and their ratios to total unemployment for 2000 and 2023. By 2023, youth unemployment rates were significantly lower in all 11 countries compared to 2000. The country ranking shows that in 2000, the highest rates were in Croatia, Poland, and Slovakia, while the lowest were observed in Czechia, Hungary, and Slovenia. By 2023, Croatia, Romania, and Slovakia reported the highest levels, whereas Czechia, Slovenia, and Poland maintained the lowest. These rankings suggest that Czechia and Slovenia consistently maintained relatively low youth unemployment rates, while Slovakia and Croatia experienced persistently high levels.

In both years, youth unemployment rates remained considerably higher than total unemployment rates. By 2023, the ratio of youth to total unemployment ranged from 1.5 to 4.07, and notably, these ratios were higher in all countries than they were in 2000. These disparities can be attributed to a greater tendency among young people to change jobs, potential mismatches between qualifications and employers' requirements, and the relatively high shares of young people in temporary employment, where dismissals are easier and less costly for employers.

Table 1. Trends in youth and total unemployment rates in CEE countries, 2000–2023 (in %)

Rank (2000)	Country	Youth unemployment rates (%)	Ratio of youth unemployment rate to total unemployment rate in 2000	Rank (2023)	Country	Youth unemployment rates (%)	Ratio of youth unemployment rate to total unemployment rate in 2023
1	Croatia	37.5	2.14	1	Romania	21.8	3.89
2	Slovakia	36.9	1.93	2	Slovakia	19.8	3.41
3	Poland	35.7	2.17	3	Croatia	18.9	3.09
4	Bulgaria	33.3	2.05	4	Estonia	17.3	2.70
5	Lithuania	28.6	1.78	5	Lithuania	13.8	2.00
6	Latvia	21.3	1.50	6	Hungary	12.8	3.12
7	Estonia	21.1	1.57	7	Latvia	12.3	1.89
8	Romania	17.8	2.50	8	Bulgaria	12.1	2.81
9	Czechia	17.0	1.93	9	Poland	11.4	4.07
10	Slovenia	16.4	2.37	10	Slovenia	9.9	2.67
11	Hungary	12.3	1.86	11	Czechia	8.3	3.19

Source: own study based on data from Eurostat Database 2025.

The volatility of youth unemployment rates depended on various economic, social, and institutional factors, with GDP growth dynamics serving as a key driver. Real GDP growth from 2000 to 2023, presented in Figure 2, exhibited considerable business cycle fluctuations. The 2000–2008 period saw high GDP growth rates (ranging from 3.5% to 7%), which contributed to falling unemployment rates. In contrast, the 2009–2013 period saw a downturn in economic conditions due to the effects of the GFC, which resulted in negative average GDP growth rates in most countries (except for Poland, Slovakia, and Bulgaria), accompanied by rising unemployment. The 2014–2019 period marked another phase of economic expansion, with average growth rates between 2.6% and 4.4%, leading to further declines in unemployment. Meanwhile, in 2020, the consequences of the COVID-19 pandemic became evident, resulting in negative GDP growth in all countries and increased unemployment in most. More recently (2021–2023), a clear economic recovery was observed, reflected in favourable average GDP growth rates ranging from 1.1% in Estonia to 7.6% in Croatia.

Trends in youth unemployment are influenced not only by output dynamics. The significance of temporary employment for the development of unemployment, particularly youth unemployment, can be derived from the natural rate of unemployment theory (Friedman 1975) and the NAIRU theory (Layard, Nickell, and Jackman 1991). Both frameworks link unemployment levels to the degree of labour market flexibility. The share of temporary employment in total employment can serve as a proxy for this flexibility. This form of employment allows employers to adjust workforce levels more quickly to market conditions than in the case of a permanent contract. It is particularly relevant to youth unemployment, given the high prevalence of temporary contracts among young workers.

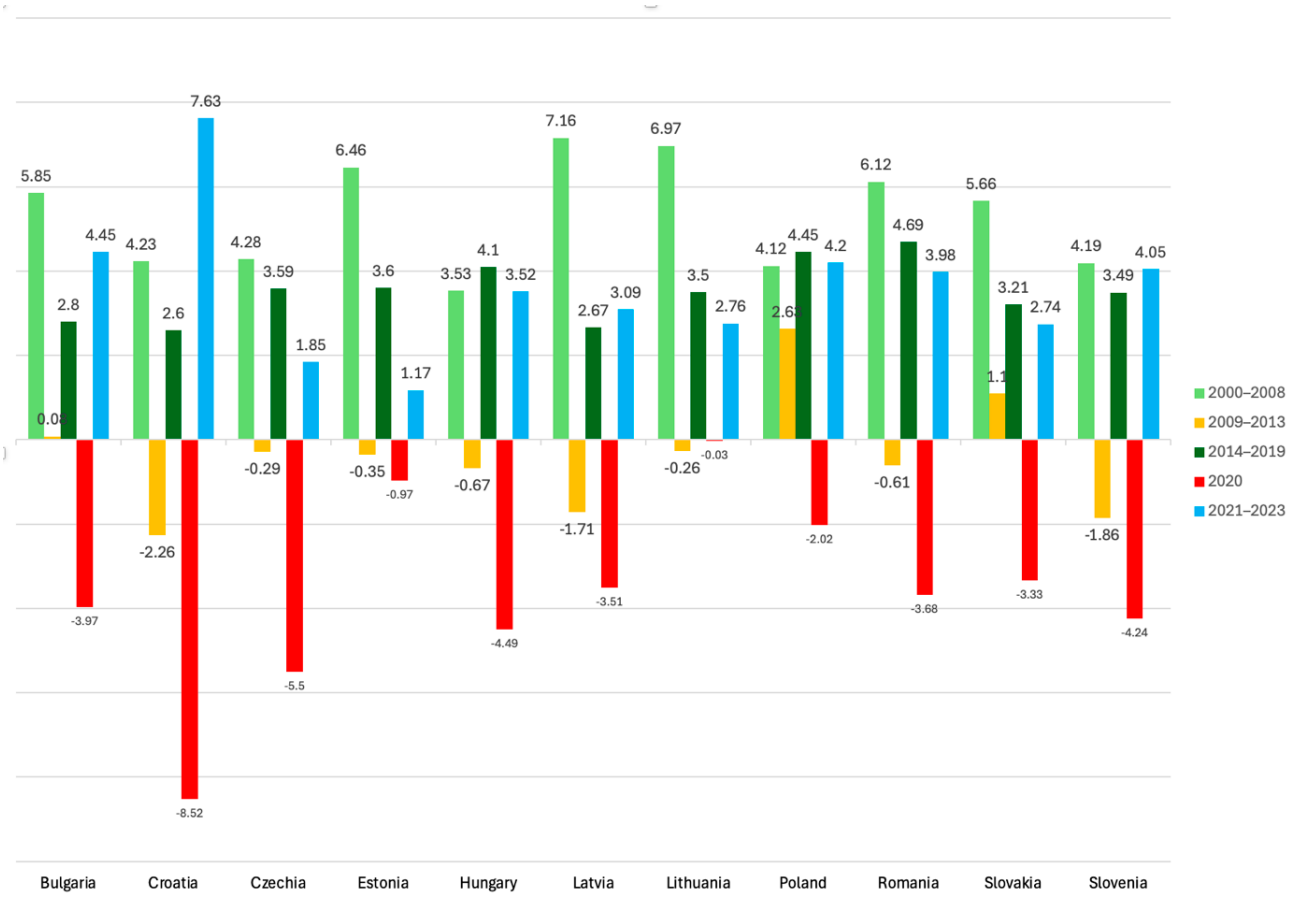


Figure 2. Average annual GDP growth rates by subperiods in CEE countries, 2000–2023 (in %)
Source: own study based on data from Eurostat Database 2025.

Figure 3 presents the average shares of temporary employment. Two main conclusions emerge. First, across all subperiods, the highest shares were recorded in Poland, Slovenia, and Croatia, while the lowest were in Romania, Estonia, and Lithuania. Second, a clear downward trend in temporary employment shares is visible in most countries, especially those with previously high rates.

The degree of legal employment protection also plays a significant role in shaping unemployment. Employment Protection Legislation (EPL) encompasses the legal regulations governing employment contracts, particularly dismissals, notice periods, and severance pay (Cahuc and Zylberberg 2004:734; Boeri and van Ours 2011:255)[1]. When these regulations are more restrictive, employers incur higher costs when dismissing employees and are thus less likely to use layoffs to adjust to market conditions. Consequently, stricter EPL may reduce layoffs and unemployment. However, this effect is not unequivocal. Increasing the legal restrictiveness can lead to inefficient labour allocation and reduced business profitability, which may ultimately necessitate reductions in employment (Greenwald and Stiglitz 1995; Malul et al. 2011).

1 For a broader discussion on employment protection legislation, see Kwiatkowski and Włodarczyk 2012.

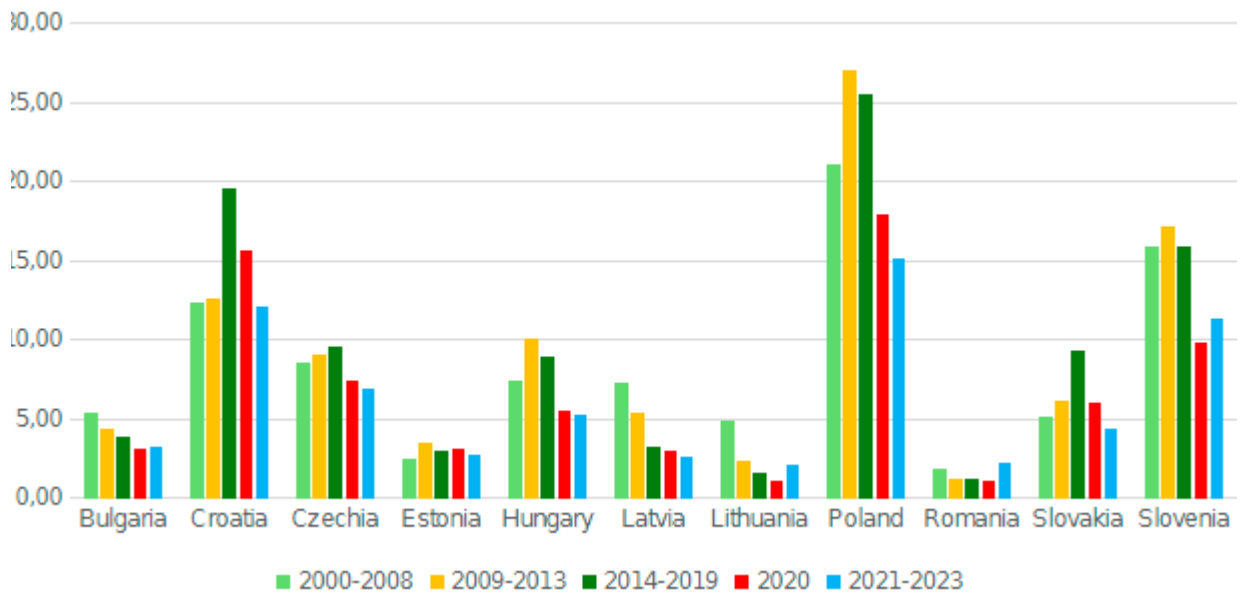


Figure 3. Average shares of temporary employment by subperiods in 2000–2023 (as % of total employment)
Source: own study based on data from Eurostat Database 2025.

Table 2. EPL indices for permanent (A) and temporary (B) employment contracts in 2008, 2014, and 2019

Country		2008	2014	2019
Czechia	A	2.99	2.90	2.90
	B	1.88	2.13	2.13
Latvia	A	–	3.10	3.10
	B	–	1.79	1.79
Lithuania	A	–	2.53	2.25
	B	–	3.21	1.92
Poland	A	2.43	2.43	2.43
	B	2.21	2.21	2.21
Slovakia	A	3.06	2.68	2.68
	B	2.17	2.42	2.75
Slovenia	A	2.77	2.41	2.41
	B	2.50	2.13	2.13

Source: own study based on data from OECD n.d., *OECD Data Explorer*.

Table 2 presents EPL indices for temporary and permanent employment contracts in the CEE countries that are OECD members. These indices, as estimated by the OECD up to 2019, range from 0 (no restrictions) to 6 (maximum restrictions). The data indicate notable differences in the employment protection restrictiveness among the countries, and these levels changed over time in some cases. For permanent contracts, Latvia and Czechia recorded relatively high index values, while Estonia and Lithuania recorded the lowest. In the case of temporary employment, Estonia and Slovakia maintained relatively high levels of protection, while Latvia and Slovenia reported relatively low levels.

Table 3. Youth enrolment rate in the 15–24 age group in 2013, 2019, and 2022 (in %)

Country	2013	2019	2022
Bulgaria	55.2	56.8	57.7
Czechia	63.2	65.0	69.7
Croatia	60.3	62.8	29.8*
Latvia	71.6	67.0	70.7
Lithuania	71.6	67.0	69.9
Hungary	63.6	56.7	60.2
Poland	71.8	68.6	69.9
Romania	58.9**	52.7	54.8
Slovenia	73.1	74.3	75.4
Slovakia	57.5	55.9	59.2

* Definition differs due to EU-LFS methodological change in 2021 (more detailed distinction between formal and non-formal learning).

** Definition differs due to the Romanian LFS methodological change in 2013 (due to the modification of the weighting procedure).

Source: own study based on data from Eurostat (n.d.).

The youth enrolment rate, which indicates the percentage of young people aged 15–24 still in education, also has some relevance for youth unemployment. Table 3 shows that Slovenia, Latvia, Poland, Lithuania, and Czechia had relatively high enrolment levels, whereas Romania and Bulgaria had relatively low levels.

Results of Econometric Analyses

Table 4 presents the estimates of Okun's coefficients for the eight OECD countries based on the RLM model with the Huber loss function, disaggregated by age cohort and gender.

Table 4. Estimation of Okun's coefficients, RLM model, 8 OECD countries, 2000–2023

Cohort	Okun's coefficients (γ)	Lower CI* (2.5%)	Upper CI (97.5%)
Total			
15–24	–0.4431	–0.5216	–0.3638
25–34	–0.2704	–0.3016	–0.2383
35–44	–0.2345	–0.2655	–0.2024
45–54	–0.2380	–0.2686	–0.2073
55–64	–0.2054	–0.2372	–0.1737
65–74	–0.0939	–0.1322	–0.0555
Male			
15–24	–0.4923	–0.5623	–0.4232
25–34	–0.3001	–0.3465	–0.2544

Cohort	Okun's coefficients (γ)	Lower CI* (2.5%)	Upper CI (97.5%)
35–44	–0.2607	–0.3072	–0.2143
45–54	–0.2654	–0.3102	–0.2203
55–64	–0.2342	–0.2821	–0.1864
65–74	–0.1012	–0.1503	–0.0521
Female			
15–24	–0.4012	–0.4661	–0.3363
25–34	–0.2503	–0.2954	–0.2052
35–44	–0.2156	–0.2621	–0.1691
45–54	–0.2191	–0.2640	–0.1742
55–64	–0.1934	–0.2398	–0.1470
65–74	–0.0851	–0.1312	–0.0390

* Lower/Upper CI – lower and upper bounds of the confidence interval.

Source: own calculations based on OECD n.d., *OECD Data Explorer*.

The RLM estimations revealed statistically significant Okun's coefficients across all age cohorts and genders, with consistently negative values. The highest absolute coefficients were recorded for the 15–24 cohort for the total population, as well as for women and men, while the lowest were observed for the older cohorts. A 1 p.p. increase in GDP growth is thus associated with an expected average decrease in the unemployment rate of 0.4431 p.p. for the 15–24 age group. In each cohort, the magnitude of the coefficients estimated for men was greater (i.e., more negative) than that for women. The bootstrap confidence interval (CI), based on 400 replications, confirmed the precision of the cohort-specific estimations.

Table 5. Estimation of Okun's coefficients (γ), RLM model, for the 15–24 age cohort, 8 OECD countries, 2000–2023

Country	Okun's coefficients (γ)	Lower CI (2.5%)	Upper CI (97.5%)
Total			
Czechia	–0.3851	–0.5077	–0.2676
Estonia	–0.5040	–0.7022	–0.2441
Hungary	–0.1787	–0.3945	0.0026
Latvia	–0.3758	–0.5834	–0.2345
Lithuania	–0.6437	–0.8865	–0.4293
Poland	–0.5690	–0.7894	–0.3815
Slovenia	–0.3936	–0.5183	–0.3110
Slovakia	–0.6566	–0.9113	–0.1435
Male			
Czechia	–0.3924	–0.6316	–0.2291
Estonia	–0.5342	–0.9805	0.0069

Country	Okun's coefficients (γ)	Lower CI (2.5%)	Upper CI (97.5%)
Hungary	–0.1405	–0.6919	0.0775
Latvia	–0.3202	–0.8553	–0.1364
Lithuania	–0.8432	–1.3055	–0.3046
Poland	–0.5923	–0.9791	–0.1708
Slovenia	–0.3900	–0.5707	–0.2113
Slovakia	–0.8036	–0.137	–0.2358
Female			
Czechia	–0.5178	–0.7980	–0.0855
Estonia	–0.2030	–0.5100	0.1537
Hungary	–0.4939	–0.9955	–0.1978
Latvia	–0.5135	–0.7385	–0.2101
Lithuania	–0.5353	–1.0108	–0.1284
Poland	–0.3892	–0.7320	–0.2485
Slovenia	–0.5178	–0.7980	–0.0855
Slovakia	–0.5077	–0.7398	0.1386

Source: own calculations based on OECD n.d., *OECD Data Explorer*.

Table 5 presents the RLM estimation results for the 15–24 age cohort[2], calculated separately for each of the eight OECD countries. For the total population, significant negative Okun's coefficients were obtained for all countries except Hungary, where the confidence interval contains zero. The most substantial effect was observed in Slovakia.

Gender-disaggregated analysis confirmed the existence of substantial heterogeneity. Among men, the strongest effect was found in Lithuania, representing the highest magnitude across the entire dataset. In contrast, results for Estonia and Hungary among men exhibited high uncertainty, with confidence intervals including zero. The results for women displayed greater variation. High negative estimates were observed in Czechia, Latvia, Lithuania (–0.5353), and Poland. The estimates for women were statistically insignificant in Estonia and Slovakia.

Table 6. Estimation of Okun's coefficients (γ), RLM models for the 15–24 age cohort, 3 non-OECD countries, 2009–2023

Country	Gender	Okun's coefficients (γ)	CI (2.5%)	CI (97.5%)
Bulgaria	Female	–0.898	–1.919	–0.357
Bulgaria	Male	–0.751	–2.43	0.004
Bulgaria	Total	–0.805	–2.191	–0.18
Croatia	Female	–0.448	–2.181	0.085
Croatia	Male	–0.508	–2.363	0.056

2 Full estimation results for each country and all age cohorts, for the total population, are available from the authors upon request.

Country	Gender	Okun's coefficients (γ)	CI (2.5%)	CI (97.5%)
Croatia	Total	−0.478	−2.254	0.052
Romania	Female	−0.289	−0.653	0.227
Romania	Male	−0.345	−0.456	−0.132
Romania	Total	−0.319	−0.513	−0.002

Source: own calculations based on Eurostat (n.d.).

Table 6 presents the estimation results for Bulgaria, Croatia, and Romania. In all three countries, the Okun's coefficients were negative, indicating an inverse relationship between annual GDP growth and changes in the youth unemployment rate. The effect was more substantial among women, although the confidence interval for men was wider, suggesting greater uncertainty in the estimates for this subgroup.

Table 7 presents the results of two-way fixed effects (TWFE) models for five age cohorts (15–24, 25–34, 35–44, 45–54, 55–64), disaggregated by gender, for the 2000–2023 period. The estimates for the 15–24 cohort are based on data from 11 countries, while those for the remaining cohorts are based on data from the eight OECD countries.

Table 7. Estimation of Okun's coefficients (γ), TWFE models

Cohort	Group	Okun's coefficients (γ)	SE_clustered	p	Lower CI	Upper CI	R^2
15–24	Total	−0.238	0.045	0.000	−0.303	−0.173	0.573
15–24	Men	−0.449	0.089	0.000	−0.603	−0.108	0.465
15–24	Women	−0.390	0.116	0.001	−0.586	−0.109	0.422
25–34	Total	−0.297	0.026	0.000	−0.358	−0.233	0.674
25–34	Men	−0.362	0.037	0.000	−0.464	−0.200	0.647
25–34	Women	−0.224	0.039	0.000	−0.304	−0.117	0.563
35–44	Total	−0.272	0.019	0.000	−0.324	−0.205	0.628
35–44	Men	−0.349	0.022	0.000	−0.413	−0.275	0.610
35–44	Women	−0.197	0.026	0.000	−0.258	−0.080	0.510
45–54	Total	−0.292	0.025	0.000	−0.356	−0.220	0.643
45–54	Men	−0.381	0.038	0.000	−0.460	−0.244	0.626
45–54	Women	−0.159	0.069	0.021	−0.277	−0.046	0.491
55–64	Total	−0.217	0.014	0.000	−0.268	−0.160	0.479
55–64	Men	−0.259	0.019	0.000	−0.316	−0.132	0.450
55–64	Women	−0.259	0.019	0.000	−0.320	−0.161	0.450

Source: own calculations based on Eurostat (n.d.).

The strongest unemployment response to GDP fluctuations was observed in the 25–34 age cohort for the total population, and in the 15–24 cohort for both women and men. In most cohorts,

the effect is considerably stronger among men than women. The high R^2 values confirm a good model fit.

A comparison with Table 4, which reports RLM estimates without fixed effects, indicates consistency in both the direction and hierarchy of the coefficients. In both models, the GDP – unemployment relationship is negative and strong among young people, and its intensity systematically weakens with age. The lower Okun's coefficients values in the TWFE model result from controlling for country and year effects, which remove part of the structural variability and institutional heterogeneity. Both approaches confirm that Okun's law holds consistently across the region, especially for younger cohorts and for men.

To examine whether the elasticity of Okun's law differs significantly between women and men, a Wald test for gender differences ($\Delta Y \times$ Male) was conducted. The results are presented in Table 1A in the Appendix. The findings show that gender differences in Okun's elasticity are primarily evident among younger workers, whereas in older cohorts, labour markets exhibit greater stability regardless of gender. Additionally, a Wald test confirmed statistically significant cross-country differences in the strength of the Okun effect for the youngest cohorts (Table 2A in the Appendix).

To capture changes in the relationship between economic growth and youth unemployment across subperiods, Okun's coefficients were estimated for three periods: pre-GFC (≤ 2008), post-GFC (2009–2019), and post-COVID-19 pandemic (≥ 2020) (Table 8).

Table 8. Estimation of Okun's coefficients (γ) across structural periods, cohort 15–24, 11 countries, 2000–2023

Group	Period	Okun's coefficients (γ)	SE clustered	p
Total	≤ 2008	–0.19301	0.05504	0.000454
Total	2009–2019	–0.35429	0.08822	5.92E-05
Total	≥ 2020	0.035353	0.033421	0.290137
Male	≤ 2008	–0.21179	0.119823	0.077134
Male	2009–2019	–0.80973	0.230078	0.000433
Male	≥ 2020	0.129714	0.147548	0.379331
Female	≤ 2008	–0.25037	0.196027	0.201524
Female	2009–2019	–0.59562	0.155802	0.000132
Female	≥ 2020	–0.06966	0.184331	0.705479

Source: own calculations based on Eurostat (n.d.).

The results indicate that in the pre-GFC period, Okun's law exhibited moderate strength for the total youth population. Between 2009 and 2019, this relationship became markedly stronger, reflecting greater labour market sensitivity to economic fluctuations following the GFC. This may have been related to increased emigration of young people in some countries after EU accession, particularly in Romania and Poland. After 2020, the sign of the coefficient becomes positive but statistically insignificant. By gender, the results show that the Okun coefficient was more negative

for men from 2009 to 2019. These findings suggest that after 2020, the relationship between economic growth and youth unemployment weakened.

Table 9 presents estimates from the interactive Okun's law model, which includes an interaction with the share of temporary employment in total employment. The model was estimated for the 15–24 age cohort for the period 2000–2023, covering the eleven CEE countries.

Table 9. Estimates from the interactive Okun's law model with the share of temporary employment

Group	ΔY (β_1)	SE (clustered)	p	ΔY×TEMP (β_2)	SE (clustered)	p	N
Total	−0.242	0.053	0.001	+0.102	0.040	0.019	253
Male	−0.305	0.069	0.000	+0.118	0.045	0.012	253
Female	−0.182	0.060	0.004	+0.027	0.041	0.511	253

Source: own calculations based on Eurostat (n.d.).

As shown in Table 9, the coefficients for ΔY (β_1) are negative and statistically significant across all groups, confirming that GDP growth led to a decline in youth unemployment, in line with the classical Okun's law. The β_2 coefficients are positive, indicating that a higher share of temporary employment weakens the traditional Okun effect; the greater the proportion of workers on temporary contracts, the weaker the decline in youth unemployment in response to GDP growth. For women, however, the interaction term is not statistically significant.

The results of the interactive model with the enrolment rate (ENROL) for the 15–24 age cohort also confirm the validity of Okun's law, while showing a significant modification in the strength of this relationship based on educational enrolment levels.

Table 10. Estimates from the interactive TWFE Okun's law model with the enrolment rate, 15–24 cohort, 9 countries*, 2013–2023

Group	ΔY (β_1)	SE (clustered)	p	ΔY×ENROL (β_2)	SE (clustered)	p	N
Total	−0.261	0.059	0.001	−0.077	0.031	0.027	99
Male	−0.315	0.071	0.000	−0.085	0.036	0.022	99
Female	−0.193	0.065	0.005	−0.049	0.040	0.226	99

* The data about enrolment rates were available for 9 countries: Bulgaria, Croatia, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia.

Source: own calculations based on Eurostat (n.d.).

The coefficient for ΔY (β_1) is negative and statistically significant. The negative and significant interaction coefficient β_2 indicates that the Okun relationship strengthens with higher levels of educational enrolment; the greater the share of young people continuing education, the stronger the response of unemployment to GDP changes. This effect is particularly pronounced among men, while in the female group, the interaction does not reach statistical significance.

The results of the interactive model that incorporates the EPL index for permanent contracts (EPL A) indicate that Okun's law holds during the analysed period.

Table 11. Estimates from the interactive TWFE model with EPL A indices, cohort 15–24, 8 OECD countries, 2013–2019

Group	ΔY (β_1)	SE (clustered)	p	ΔY×EPL A (β_2)	SE (clustered)	p	N
Total	−0.302	0.064	0.001	+0.066	0.028	0.029	56
Male	−0.349	0.071	0.001	+0.084	0.034	0.017	56
Female	−0.236	0.069	0.006	+0.047	0.037	0.188	56

Source: own calculations based on OECD n.d., *OECD Indicators*...

The coefficients for ΔY (β_1) are negative and statistically significant across all groups, confirming that GDP growth is associated with a decline in youth unemployment. The positive and significant interaction coefficients (β_2) indicate that a higher level of employment protection for workers on permanent contracts weakens the classical Okun effect. In countries and years with more restrictive employment regulations (higher EPL A), GDP growth leads to a smaller decrease in youth unemployment. This effect is particularly evident among men, while in the female group it remains statistically insignificant. In the interactive Okun's law model, which includes the EPL B index (Table 12), the coefficients for ΔY (β_1) are negative and statistically significant across all groups, confirming that GDP growth reduces youth unemployment.

Table 12. Estimates from the interactive TWFE model with EPL B indices, 2013–2019, 8 CEE countries, cohort 15–24

Group	ΔY (β_1)	SE (clustered)	p	ΔY×EPL B (β_2)	SE (clustered)	p	N
Total	−0.258	0.063	0.001	−0.041	0.019	0.036	56
Male	−0.241	0.019	0.036	−0.052	0.022	0.021	56
Female	−0.197	0.067	0.007	−0.031	0.024	0.192	56

Source: own calculations based on OECD n.d., *OECD Indicators*...

Negative interaction coefficients (β_2) indicate that a higher level of regulatory strictness regarding temporary contracts (EPL B) strengthens the Okun effect; the stronger the protection of fixed-term employees, the greater the decline in youth unemployment in response to economic growth. In the female group, the interaction remains statistically insignificant.

Discussion

The analyses allow for several generalisations regarding youth unemployment and its determinants in the examined CEE countries.

In all countries, the unemployment rates for youth aged 15–24 significantly exceeded the corresponding rates for the entire labour force. This prompted an investigation into the causes of this disparity in the unique characteristics of youth in the labour market. Undoubtedly, relatively limited work experience, a high propensity to change jobs in search of suitable employment, and a relatively high share of youth in various forms of temporary employment, which is less protected

than regular employment under permanent contracts, typically held by individuals with longer work experience, all play a key role.

The analyses revealed substantial variation in youth unemployment rates across the CEE countries. These differences are undoubtedly linked to varying GDP growth dynamics and institutional frameworks. Countries with relatively high youth unemployment rates from 2000 to 2023 include Croatia, Poland, and Slovakia. In Croatia, strong fluctuations in GDP growth contributed to this with periods of expansion followed by contractions, such as between 2009 and 2013 (average annual GDP decline of –2.2%) and in 2020 (–8.5%). Moreover, a relatively high share of temporary employment supported the elevated youth unemployment rate. In Poland, despite sustained economic growth (only one GDP decline in 2020 at –2.02%) and relatively high enrolment rates, youth unemployment remained high, which can be attributed to the prevalence of temporary contracts and weaker legal protection compared to regular employment. In Slovakia, where GDP fell only in 2020 (–3.3%), low youth enrolment rates contributed to higher youth unemployment.

Countries with relatively low youth unemployment rates throughout the period included Estonia, Hungary, and Slovenia. In Estonia, relatively high GDP growth rates (1.1% to 6.4%) alternated with moderate declines (–0.3% annually from 2009–2013, and –0.9% in 2020), alongside low temporary employment shares and relatively high EPL indices for regular employment.

In Hungary and Slovenia, the drivers of low youth unemployment were more closely aligned. In Hungary, young people registered at Public Employment Service offices can receive various support under the "Youth Guarantee Plan" (including subsidized job offers, internships, and vocational training), improving their situation in the labor market (Farkas et. al. 2020: 8). In Slovenia, despite high shares of temporary employment and GDP contractions between 2009 and 2013 (–1.8% annually) and in 2020 (–4.2%), youth unemployment remained relatively low. This was due to high GDP growth in other years (ranging from 3.4% to 4.1%), high enrolment rates, and relatively strong employment protection for regular contracts.

The sensitivity of unemployment to GDP changes, estimated across various age cohorts in a pooled model for the eight OECD countries, not only confirmed a relationship consistent with Okun's Law but also revealed cohort-specific differences. The strongest negative relationship was observed in the 15–24 age group, with progressively weaker responses in older cohorts. This result aligns with the findings of Hutengs and Stadtmann (2013), Dunsch (2016), and Butkus and Seputiene (2019). For young people, characteristics such as greater labour market mobility due to job searching and insufficient work experience became evident. Moreover, early in their careers, young people are often employed under temporary contracts, which are less protected legally than permanent contracts (Kwiatkowski 2016; Kwiatkowski and Włodarczyk 2017). As a result, during economic downturns, young workers are the first to be dismissed.

The pooled model also revealed gender differences in unemployment sensitivity to GDP changes. In all age cohorts, the absolute values of Okun coefficients were higher for men than for women. Some differences between men and women with regard to the cyclical sensitivity of unemployment were also noted by Zanin (2014). This can be explained by sectoral differences in employment structures and the varying cyclical sensitivity of different sectors. Previous

studies show that industry and construction are much more cyclical than the service sector (Kwiatkowski and Kucharski 2009). As such, male-dominated sectors like industry and construction contribute to the higher cyclical sensitivity of male unemployment compared to female unemployment.

Cohort models for individual OECD countries confirmed a negative relationship between GDP growth and unemployment across all age cohorts. They also confirmed the highest cyclical sensitivity in the youngest group (15–24) and a gradually weaker, though still negative, relationship in older groups. Some cross-country differences in the absolute values of Okun coefficients in the 15–24 group were observed: the strongest negative relationship was in Slovakia (characterised by a high share of temporary employment, low enrolment rates, but relatively high EPL indices for regular jobs) and Lithuania (low EPL for regular jobs, low shares of temporary jobs, and high enrolment rates). Conversely, weaker effects were noted in Czechia (high EPL and high enrolment) and Slovenia (high EPL and high enrolment). These observations suggest that theoretical expectations regarding institutional labour market influences are not always confirmed. Slovakia is a fascinating case, where strong cyclical youth unemployment sensitivity occurred despite strong legal protection of permanent employment contracts. This may support the hypothesis that overly restrictive EPL can result in inefficient labour allocation, employment cuts, rising unemployment, and a relatively high popularity of temporary employment in that country.

Estimates for Bulgaria, Croatia, and Romania confirm the negative relationship between GDP growth and unemployment rates across all age cohorts, with the most substantial adverse effect observed in the youngest group and progressively weaker effects in older groups. Powerful negative relationships were found in Bulgaria, where, unlike other countries, the cyclical sensitivity of female unemployment exceeded that of males.

The estimates of structural and institutional factors yielded results only partially consistent with theoretical expectations. As expected, higher EPL indices for permanent contracts reduce the sensitivity of youth unemployment to changes in GDP. Stricter employment protection tends to stabilise both employment and unemployment. Similarly, the increased sensitivity of youth unemployment associated with higher enrolment rates can be explained by the fact that a higher GDP growth rate translates into a stronger reduction in youth unemployment when more young people remain in education.

However, the impact of temporary employment on youth unemployment sensitivity proved contrary to expectations. The weaker responsiveness of unemployment may be linked to the relatively small share of temporary employment compared with permanent employment, as well as its downward trend over the analysed period. Likewise, the effect of EPL indices for temporary contracts on unemployment sensitivity was opposite to theoretical assumptions. The finding that stricter legal protection of temporary employment increases the responsiveness of youth unemployment to GDP changes supports the hypothesis of Malul et al. (2011) regarding the negative labour market effects of excessive employment protection.

Conclusion

The analysis of CEE labour markets between 2000 and 2023 confirms the precarious situation that young people face within these economies. In all the analysed countries, unemployment rates among young people aged 15–24 were higher than both the total unemployment rates and the rates observed in older age groups. This trend was especially pronounced in Croatia, Poland, and Slovakia, indicating that typical characteristics of youth, such as limited work experience and relatively high labour market mobility, play an important role in job search and retention. In Croatia and Poland, the prevalence of youth unemployment was further fuelled by the extensive use of temporary employment systems that attracted many young workers. In contrast, in Slovakia, the relatively low enrolment rate among youth was a contributing factor.

The analysis also showed substantial fluctuations in youth unemployment rates throughout the studied period. These fluctuations were undoubtedly linked primarily to fluctuations in GDP growth rates and high shares of temporary employment in total employment in several countries.

Econometric results revealed a high degree of cyclical sensitivity of youth unemployment to GDP changes, confirming the validity of Okun's Law. In the pooled model for the eight CEE countries, the 15–24 age cohort exhibited the strongest negative relationship between the unemployment rate and GDP growth. This negative relationship was still present in older cohorts, but weakened progressively with age. Additionally, the relationship was stronger for men than for women, which may be attributed to the sectoral distribution of male and female employment, with men more likely to work in sectors that are more sensitive to economic fluctuations.

Cohort-based models for individual countries also confirmed a negative relationship between GDP growth and unemployment across all age groups, with the strongest relationship in the 15–24 age group. A cross-country comparison shows that the strongest negative relationships for this age group were found in Lithuania, Poland, and Slovakia (for both the total cohort and for men), while the weakest were in Czechia and Slovenia. For women, the strongest sensitivity was observed in Czechia, Latvia, and Lithuania, while the weakest was in Estonia and Poland. Attempts to explain cross-country differences in estimates based on data on temporary employment, EPL indices, and enrolment rates proved only partially successful, suggesting a need for further investigation.

Similarly, cohort analyses in the three non-OECD countries Bulgaria, Croatia, and Romania confirmed the presence of Okun's Law, particularly in the 15–24 age group, where the negative relationship between the analysed variables was the strongest. Unlike in the other countries, the negative relationship for women in these cases was stronger than for men, which calls for a separate, dedicated analysis.

Finally, the results of the interactive models confirm that Okun's law holds in CEE countries; however, its strength depends on the structural and institutional characteristics of the labour market. A high share of temporary employment weakens the classical Okun's effect, whereas a higher level of young people remaining in education amplifies the responsiveness of unemployment to changes in GDP. Furthermore, stricter employment protection for permanent contracts (EPL A) mitigates this relationship, while stronger regulations for temporary contracts (EPL B) reinforce it.

Appendix

Table 1A. Wald test for gender differences (ΔY×Male)

Cohort	Test	p
15–24	F(1, 7) = 3.94	0.082
25–34	F(1, 7) = 3.61	0.093
35–44	F(1, 7) = 2.12	0.184
45–54	F(1, 7) = 0.84	0.389
55–64	F(1, 7) = 0.55	0.486

Source: own calculations based on Eurostat (n.d.).

Table 2A. Wald test for slope heterogeneity (ΔY×Country$_i$)

Cohort	Test	p
15–24	F(7, 240) = 2.18	0.037
25–34	F(7, 240) = 2.44	0.028
35–44	F(7, 240) = 1.91	0.068
45–54	F(7, 240) = 1.57	0.135
55–64	F(7, 240) = 1.22	0.283

Source: own calculations based on Eurostat (n.d.).

References

Arellano, M. (1987), *PRACTITIONERS' CORNER: Computing Robust Standard Errors for Within-groups Estimators*, "Oxford Bulletin of Economics and Statistics", 49 (4), pp. 431–434, https://doi.org/10.1111/j.1468-0084.1987.mp49004006.x

Bartosik, K. (2020), *Temporary contracts and Okun's law in Poland*, "Equilibrium. Quarterly Journal of Economics and Economic Policy", 15 (4), pp. 735–760, https://doi.org/10.24136/eq.2020.032

Blanchard, O. (1997), *The Economics of Post-Communist Transition*, Clarendon Press, Oxford, https://doi.org/10.1093/0198293992.001.0001

Boeri, T., Ours, J. van (2011), *Ekonomia niedoskonałych rynków pracy*, Wolters Kluwer Polska, Warszawa.

Butkus, M., Seputiene, J. (2019), *The Output Gap and Youth Unemployment: An Analysis Based on Okun's Law*, "Economies", 7 (10), pp. 1–17, https://doi.org/10.3390/economies7040108

Cahuc, P., Zylberberg, A. (2004), *Labour economics*, The MIT Press, Cambridge.

Cazes, S., Nesporova, A. (2004), *Labour markets in transition: balancing flexibility and security in Central and Eastern Europe*, "Revue de l'OFCE", April (Special Issue), pp. 23–54, https://doi.org/10.3917/reof.075.0023

Croissant, Y., Millo, G. (2008), *Panel Data Econometrics in R: The plm Package*, "Journal of Statistical Software", 27 (2), pp. 1–43, https://doi.org/10.18637/jss.v027.i02

Dunsch, S. (2016), *Okun's Law and Youth Unemployment in Germany and Poland*, "International Journal of Management and Economics", 49 (1), pp. 34–57, https://doi.org/10.1515/ijme-2016-0003

Efron, B., Tibshirani, R.J. (1994), *An Introduction to the Bootstrap*, Chapman & Hall/CRC, New York, https://doi.org/10.1201/9780429246593

Eurostat (n.d.), *Data Browser*, https://ec.europa.eu/eurostat/databrowser/ (accessed: 22.03.2025).

Farkas, Z., Racz, A., Sik, D., Sagi, J. (2020), *COST CA18213 Rural NEETs in Hungary: 2009/2019 Overview*, https://rnyobservatory.eu/web/National-Reports/NR-HUNGARY-09-19.pdf (accessed: 25.03.2025).

Friedman, M. (1975), *Rola polityki pieniężnej*, [in:] A. Szeworski (ed.), *Teoria i polityka stabilizacji koniunktury. Wybór tekstów*, PWE, Warszawa, pp. 260–284.

Gajderowicz, T., Grotkowska, G., Wincenciak, L., Wirtek, E. (2014), *Wrażliwość stóp bezrobocia względem wahań PKB w przekroju województw*, "Ekonomia", 39, pp. 29–58.

Gozgor, G. (2013), *Testing Unemployment Persistence in Central and Eastern European Countries*, "International Journal of Economics and Financial Issues", 3 (3), pp. 694–700, https://www.econjournals.com/index.php/ijefi/article/view/497 (accessed: 25.03.2025).

Greenwald, B.C., Stiglitz, J.E. (1995), *Labour Market Adjustments and the Persistence of Unemployment*, "AEA Papers and Proceedings", 85 (2).

Guzikowski, M. (2016), *Instytucje rynku pracy w krajach transformacyjnych*, Oficyna Wydawnicza Szkoła Główna Handlowa, Warszawa.

Huber, P.J. (1964), *Robust Estimation of a Location Parameter*, "Annals of Mathematical Statistics", 35 (1), pp. 73–101, https://doi.org/10.1214/aoms/1177703732

Hutengs, O., Stadtmann, G. (2013), *Don't trust anybody over 30: Youth unemployment and Okun's law in CEE countries*, "Discussion Paper", 333, European University Viadrina, Department of Business Administration and Economics, Frankfurt (Oder).

Keynes, J.M. (1985), *Ogólna teoria zatrudnienia, procentu i pieniądza*, PWN, Warszawa.

Kwiatkowski, E. (2016), *Controversies on the Economic Effects of Fixed-term Employment – Evidence from the OECD Countries*, "Olsztyn Economic Journal", 11 (3), pp. 195–210, https://doi.org/10.31648/oej.2924

Kwiatkowski, E., Kucharski, L. (2009), *Zmiany koniunktury gospodarczej a tendencje rozwoju sektorów i działów gospodarki polskiej w latach 1998–2008*, [in:] J.L. Bednarczyk, S.I. Bukowski, J. Misala (eds.), *Globalne rynki finansowe w dobie kryzysu*, CeDeWu, Warszawa, pp. 201–216.

Kwiatkowski, E., Włodarczyk, P. (2012), *Wpływ prawnej ochrony zatrudnienia na rynek pracy w warunkach negatywnego szoku ekonomicznego*, "Gospodarka Narodowa", 80 (11–12), pp. 1–23.

Kwiatkowski, E., Włodarczyk, P. (2014), *Importance of Employment Protection and Types of Employment Contracts for Elasticity of Employment in the OECD Countries*, "Comparative Economic Research. Central and Eastern Europe", 17 (1), pp. 21–44, https://doi.org/10.2478/cer-2014-0002

Kwiatkowski, E., Włodarczyk, P. (2017), *Rodzaje umów o pracę a elastyczność zatrudnienia w nowych krajach członkowskich Unii Europejskiej w latach 2000–2014*, "Acta Universitatis Lodziensis. Folia Oeconomica", 2 (328), pp. 163–183, https://doi.org/10.18778/0208-6018.328.11

Layard, R., Nickell, S., Jackman, R. (1991), *Unemployment: Macroeconomic Performance and the Labour Market*, Oxford University Press, Oxford.

Malul, M., Rosenboim, M., Shavit, T., Tarba, P.Y. (2011), *The role of employment protection during an exogenous shock to an economy*, "World Economy", 34 (11), pp. 1923–1935.

Nesporova, A. (2002), *Why unemployment remains so high in Central and Eastern Europe*, "ILO Employment Paper", 43, International Labour Office, Geneva.

O'Reilly, J., Eichorst, W., Gabos, A., Hadjivassiliou, K., Lain, D., Leschke, J., McGuinness, S., Kurekova, L.M., Nazio, T., Ortlieb, R., Russell, H., Villa, P. (2015), *Five Characteristics of Youth Unemployment in Europe: Flexibility, Education, Migration, Family Legacies, and EU Policy*, "SAGE Open" 2015, 5 (1), pp. 1–19, https://doi.org/10.1177/2158244015574962

OECD (n.d.), *OECD Data Explorer*, https://data-explorer.oecd.org/ (accessed: 12.02.2025).

OECD (n.d.), *OECD Indicators of Employment Protection*, https://www.oecd.org/en/data/datasets/oecd-indicators-of-employment-protection.html (accessed: 20.10.2025).

Okun, A. (1962), *Potential GNP: Its measurement and significance*, "Cowles Foundation Paper", 190, Yale University, New Haven.

R Core Team (2025), *R: A Language and Environment for Statistical Computing. Reference Index*, https://cran.r-project.org/doc/manuals/r-release/fullrefman.pdf (accessed: 22.03.2025).

Soylu, O.B., Çakmak, I., Okur, F. (2018), *Economic growth and unemployment issue: Panel data analysis in Eastern European Countries*, "Journal of International Studies", 11 (1), pp. 93–107, https://doi.org/10.14254/2071-8330.2018/11-1/7

Verardi, V., Croux, C., *Robust Regression in Stata*, "Stata Journal" 2009, 9 (3), pp. 439–453, https://doi.org/10.1177/1536867X0900900306

Zanin, L. (2014), *On Okun's law in OECD countries: An analysis by age cohorts*, "Economics Letters", 125 (2), pp. 243–248, https://doi.org/10.1016/j.econlet.2014.08.030

Bezrobocie młodzieży w krajach Europy Środkowo-Wschodniej. Czy prawo Okuna działa?

Artykuł analizuje empiryczną zasadność prawa Okuna w kontekście bezrobocia młodzieży w krajach Europy Środkowo-Wschodniej w latach 2000–2023. Badaniem objęto 11 państw, wykorzystując dane panelowe z rozbiciem na kohorty wiekowe oraz płeć. W analizie zastosowano odporne modele regresji liniowej (RLM) z funkcją straty Hubera oraz modele z efektami stałymi (TWFE). Główna uwaga została poświęcona kohorcie wiekowej 15–24 lata. Wyniki wskazują na istotną statystycznie negatywną zależność pomiędzy wzrostem gospodarczym a stopą bezrobocia młodzieży w większości analizowanych krajów, przy czym obserwuje się wyraźne zróżnicowanie zarówno między krajami, jak i ze względu na płeć. Prawo Okuna znajduje potwierdzenie w danych empirycznych, najsilniejsze efekty zaobserwowano w krajach bałtyckich oraz w Polsce, natomiast najsłabsze na Węgrzech i w Rumunii. Badanie pokazuje również, że wyższy udział zatrudnienia tymczasowego oraz wyższe wartości wskaźnika EPL dla umów na czas nieokreślony zmniejszają wrażliwość bezrobocia młodzieży na zmiany PKB, natomiast wyższe wskaźniki skolaryzacji młodzieży i wyższe wartości EPL dla umów tymczasowych zwiększają tę wrażliwość.

Słowa kluczowe: bezrobocie młodzieży, prawo Okuna, Europa Środkowo-Wschodnia, regresje panelowe