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CONTENTS

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CONTENTS

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Editorial introduction

The statement that progress in contemporary economics largely relies on the ability of economists (and their computers) to process various datasets is trivial. This is no surprise, as evolving IT capabilities are continuously transforming the methodological toolkit in almost all scientific disciplines. However, when one examines a particular economic study that pushes the boundaries of what is possible to analyse, it is easy to feel astonished. The journal's editors hope that at least some of the studies presented in the current issue of *Economics and Business Review* will serve as such an inspiration. This issue consists of six articles written by fifteen researchers working in Algeria, North Macedonia, Poland, South Korea, Ukraine, and the USA. A systematic review of 1,248 articles, estimates for 150,000 companies, or the application of the dynamic time warping method are among the topics that may captivate the journal's readers. The editors encourage followers to explore these contributions.

The current issue opens with an article by Błażej Suproń (**Environmental pollution and economic growth in the European Union countries: A systematic literature review**), whose objective is to verify whether the Environmental Kuznets Curve (EKC) hypothesis offers an accurate explanation for GDP-CO_2 relationships. The investigation encompasses 1,248 papers utilising a sample of the European Union countries. However, the answer to the research question is only partly affirmative. The study's findings suggest a refinement of the EKC hypothesis by introducing moderating factors, such as international trade and renewable energy. The choice of empirical strategy also emerges as a pivotal element. The insights derived from this study are expected to be of particular interest to researchers in the field of environmental economics, as well as to policymakers and bureaucrats involved in the formulation and implementation of environmental policies.

The second article, **Energy mix and its implications on the Vietnamese economy by 2030: A CGE analysis using GTAP-E-Power**, by Duy Chinh Nguyen and Jong-Hwan Ko, examines the economic and environmental effects of different energy generation scenarios in Vietnam. Using the GTAP-E-Power model, the study analyses three scenarios for 2030: (1) low-coal, high-gas, (2) low-coal, high-renewables, and (3) high-coal. The findings indicate that Scenario 2 (low-coal, high-renewables) is the most balanced, leading to a 1.02% GDP decline and a 0.78% increase in CO_2 emissions, while still improving the trade balance. The study highlights the sensitivity of the electronics

sector to energy shifts and the resilience of coal mining. These results provide insights for policymakers on transitioning toward a sustainable energy mix in Vietnam.

In their paper titled **The impact of women's economic empowerment on human development in sub-Saharan Africa: A panel quantile regression approach**, Lotfi Mekhzoumi, Sabrina Chikh-Amnache, and Nabila Mekhzoumi consider various indicators of women's economic empowerment, including marriage rights, parenting rights, mobility, and workplace participation. The empirical method adopted enables them to identify nuanced conclusions across quintiles. The study's findings, when broadly considered, indicate a favourable impact of women's economic empowerment on human development. The study provides valuable insights relevant to the implementation of the Sustainable Development Goals (SDGs), particularly SDG 5 Gender Equality and SDG 8 Decent Work and Economic Growth.

The subsequent article, entitled **The effects of COVID-19 on Polish enterprises** and written by Wojciech Kuryłek and Yochanan Shachmurove, examines the economic consequences of the pandemic on 150,000 Polish enterprises. Utilising financial data from the Polish National Court Register, the study takes a granular approach to assess sector-specific impacts. It compares financial ratios using Wilcoxon and Mann-Whitney tests to measure changes in profitability, liquidity, working capital, and leverage. The study highlights sectoral disparities and the crucial role of government interventions in economic recovery. The authors emphasise that the government's Anti-Crisis Shield measures, including subsidies, tax deferrals, and loan guarantees, helped mitigate some negative effects.

Magdalena Szyszko, Aleksandra Rutkowska, and Olena Motuzka's article entitled **Inflation expectations proprieties during the war: The case of Ukraine** investigates how inflation expectations evolved in Ukraine before and during the Russian invasion. Using entropy-based measures and dynamic time warping, the study examines the co-movements of expectations with inflation, food inflation, exchange rates, and production. The analysis, covering May 2019 to December 2024, finds that during the war, professional and consumer expectations became more aligned. Despite expectations remaining forward-oriented, their accuracy declined. These findings provide valuable insights for policymakers in managing inflation expectations during economic crises.

The final paper of the issue, **Financial inclusion, market concentration and underwriting performance: Empirical evidence from Central Eastern and Southeastern European countries**, authored by Bojan Srbinoski, Jordan Kjosevski, Klime Poposki, and Stevcho Mecheski, explores the relationship between financial inclusion and underwriting performance in non-life insurance markets. The findings indicate that the impact of financial inclusion on underwriting performance is contingent on the adopted method of inclusion

measurement. Additionally, the analysis reveals that market concentration serves as a moderating factor in the examined relationship. The results of this study are of particular relevance to policymakers and regulators responsible for insurance markets with deficiencies in financial inclusiveness and market competition.

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Environmental pollution and economic growth in the European Union countries: A systematic literature review

Błażej Suproń[1]

Abstract

This study presents a comprehensive analysis of the relationship between economic growth and CO_2 emissions in the European Union, with a particular focus on the Environmental Kuznets Curve (EKC) hypothesis. Through a systematic review of approximately 1,250 scientific publications, machine learning techniques, and multivariate statistical analysis, significant yet complex relationships between these variables have been identified. While the EKC hypothesis often posits a U-shaped or N-shaped relationship, the findings of this research indicate that the actual relationship can vary depending on factors such as foreign trade, energy consumption, and econometric methodologies. Numerous studies emphasise the importance of integrating renewable energy into these models. Overall, the results suggest that the EKC may be insufficient to fully comprehend the intricacies of sector-specific environmental-economic dynamics within the EU.

Keywords

- environment
- Kuznets curve
- economic growth
- European Union
- CO_2
- energy
- systematic review

JEL codes: C1, C55, O44, Q56

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Introduction

Environmental pollution resulting from human economic activity gained significant international attention at the 1979 World Climate Conference in Geneva, which underscored the rising levels of greenhouse gases and their climatic impacts (Newell & Paterson, 1996). This concern prompted major global initiatives, including the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and the Kyoto Protocol in 1997, aimed at reducing emissions and enhancing environmental protection (Böhringer, 2003). While the 2015 Paris Agreement set ambitious targets to limit temperature increases at below 2°C, some researchers argue that these efforts remain inadequate (Schleussner et al., 2016; Spreng & Spreng, 2019).

The European Union plays a leading role in climate action through the Green Deal, which sets stricter targets: climate neutrality by 2050 and a 55% reduction in greenhouse gas emissions by 2030 (compared to 1990 levels), alongside increasing renewable energy to at least 40% by 2030 (Szpilko & Ejdys, 2022). Beyond climate policy, the Green Deal drives transformations in energy, industry, and finance, reshaping economic and social landscapes (Samper et al., 2021; Vela Almeida et al., 2023). Understanding these dynamics is crucial for evidence-based policymaking that balances economic growth with climate goals.

Given the central role of economic activity in greenhouse gas emissions, understanding its relationship with environmental degradation is crucial, particularly considering the EU's climate targets. Despite over 6,000 related articles having been published between 2014 and 2024 (BASE database), gaps remain in integrating economic theory, systematic reviews, and advanced analytics. Bridging these gaps is essential for aligning economic and environmental goals. Additionally, advanced technologies like text mining and machine learning are increasingly vital for extracting insights from this extensive literature.

This study synthesises research from 2014 to 2024, integrating theoretical and empirical insights to examine the relationship between economic growth and CO_2 emissions in the EU. It has four key objectives. Firstly, it identifies primary research areas on economic growth and environmental factors, with a focus on the Environmental Kuznets Curve (EKC) hypothesis. Secondly, it applies advanced statistical tools to uncover interrelationships among key topics. Thirdly, it evaluates how theoretical frameworks shape approaches to global warming, particularly through EKC insights. Lastly, it critically assesses the economic impact of CO_2 emissions in the EU, highlighting research gaps and future directions.

The present study makes several key contributions to the existing body of knowledge. Firstly, it examines the European Union, a region with uniquely

ambitious climate targets, thus offering a valuable case study on economic-environmental dynamics. Secondly, it applies advanced methodologies, including the machine learning-based LitsearchR, for systematic review automation and multivariate techniques such as log-linear analysis and Multiple Correspondence Analysis, enhancing analytical depth. Thirdly, by leveraging data from major global databases, it overcomes the limitations of earlier reviews reliant on narrower sources. Lastly, integrating systematic and synthetic reviews with naïve search models reduces bias, providing a more balanced research perspective.

The article is structured as follows: Section 1 explores the theoretical foundations of the environmental-economic relationship; Section 2 details the methodology, including data collection and analysis; Section 3 presents the results, followed by a comparison with existing studies in Section 4; last Section concludes with key implications and future research directions.

1. Literature review

The relationship between economic growth and environmental pollution has been a subject of intense academic scrutiny. The concept of the Environmental Kuznets Curve originates from Kuznets' (1955) hypothesis on income inequality, which was later adapted to environmental economics by Grossman and Krueger (1991). The EKC suggests that in the early stages of economic development, environmental degradation intensifies with increasing GDP per capita. However, after reaching a certain income threshold, further economic growth leads to improvements in environmental quality due to technological advancements, regulatory policies, and shifts toward service-based economies (Panayotou, 1993).

Several modifications to the original EKC framework have emerged. Some studies indicate a U-shaped or N-shaped relationship between GDP and CO_2 emissions (Brock & Taylor, 2010; Fakher et al., 2023; Kaika & Zervas, 2013; Leal & Marques, 2022), while others question the universality of the EKC, arguing that factors such as energy consumption, regional differences, trade openness, and institutional quality significantly shape the emissions trajectory (Mardani et al., 2019; Shahbaz & Sinha, 2019; Tchapchet Tchouto, 2023).

Given the emphasis in research on the impact of regional conditions on the shape and trajectory of the EKC curve, it is imperative that studies focusing on specific regions consider the heterogeneity of these conditions (Bibi & Jamil, 2021; Kaika & Zervas, 2013). Empirical research on the EKC in the EU presents mixed findings. Early studies such as Bengochea-Morancho et al. (2001) examined panel data from 1981–1995 and found that a 1% increase

in GDP raised emissions by 0.18% in middle-income EU countries and 0.97% in low-income ones.

Later studies expanded on these findings; Martínez-Zarzoso et al. (2007) demonstrated that population growth disproportionately affects emissions in newer EU members, whereas older members exhibited elasticity below one; Kasman and Duman (2015) confirmed an inverted U-shaped EKC for 27 EU countries, emphasising the role of trade openness and energy consumption; Pejović et al. (2021) used a VAR model to show that GDP growth led to short-term emission reductions in some EU countries; Onofrei et al. (2022) analysed fixed-effects panel data from 2000–2017, indicating that GDP increases marginally slow emissions growth but does not eliminate it. These discrepancies highlight the role of methodological choices and country-specific factors in shaping EKC outcomes (Leal & Marques, 2022). Given the EU's ambitious climate targets, the generalizability of EKC findings remains uncertain.

Beyond economic growth, several exogenous factors influence CO_2 emissions. A growing body of literature emphasises the importance of energy consumption patterns in EKC dynamics. Dogan and Seker (2016) found that renewable energy contributes to emission reductions, whereas non-renewable sources exacerbate environmental degradation. Al-Mulali et al. (2015) confirmed that financial development and urbanisation increase CO_2 emissions, but trade openness and renewable energy mitigate this effect.

Technological innovation is another critical factor. Stern (2017) suggested that advances in energy efficiency can decouple GDP growth from emissions, while Voumik et al. (2022) demonstrated that EU countries with higher R&D investments in green technologies show stronger evidence of EKC trends. However, other studies argue that technological progress alone is insufficient without strong regulatory frameworks (Albulescu et al., 2020; Husnain et al., 2021).

Empirical investigations of the EKC employ a variety of econometric methods, each with unique strengths and limitations, while influencing the results obtained. Methods based on regression and panel data regression are commonly used (ARDL, FMOLS, DOLS, VAR). The widespread use of these methodologies is a consequence of their capacity to address the heterogeneity that is evident at the cross-country level (Acaravci & Ozturk, 2010; Gardiner & Hajek, 2020).

Recent years have seen a shift in the focus of EU-level research, with a growing emphasis on the utilisation of new methodologies. The employment of quantile regressions and non-linear models has emerged as a pivotal approach, facilitating a more nuanced and adaptable evaluation of EKC configurations (Bilgili et al., 2016; Hasanov et al., 2021; Wang et al., 2023). The development of AI and machine learning methods has also enriched research with new methods based on neural networks (Arévalo & Antonio, 2024). Due to the intricacy of research on the relationship between economy and envi-

ronmental contamination, a comprehensive comparative analysis of EKC studies and methods is presented in Appendix A in the Supplementary materials.

To sum up the literature review and the systematic analysis presented in Appendix A, despite extensive research on the EKC, key gaps remain. Most studies focus on aggregate GDP-CO_2 relationships, overlooking sector-specific trends, while the impact of EU climate policies on EKC trends remains underexplored. Additionally, research largely neglects non-CO_2 pollutants, and the use of advanced econometric methods, such as AI-based forecasting and Bayesian inference, could improve EKC estimates. Addressing these gaps with targeted, policy-relevant research will enhance the robustness of EKC findings in the EU context.

2. Research methodology and data

Systematic reviews differ from traditional literature reviews by aiming to identify all relevant studies on a research objective while minimising selection, publication, and data extraction biases (Nightingale, 2009). They offer a transparent, replicable approach to synthesising scientific evidence, evaluating all published findings and their quality (Lame, 2019). As the digital knowledge base expands, traditional analysis of individual publications becomes increasingly complex and time-consuming (Xiao & Watson, 2019). Advances in computational algorithms and machine learning significantly enhance knowledge synthesis (Grames et al., 2019).

The synthetic literature review highlights the diverse methods and topics in studies on economic growth and CO_2 emissions. Given the vast research landscape, analysing all relevant publications required a multi-method approach integrating machine learning and multivariate statistics. Our study followed a multi-stage process, combining statistical analysis, text mining, and log-linear modelling. The research was conducted in five main stages. The entire research process is illustrated in Figure 1.

The first stage of article selection applied a set of keywords based on a comprehensive literature review. These keywords covered topics related to carbon dioxide emissions, ecological footprint, environmental degradation, and environmental quality and sustainability. They were combined with terms referring to economic growth, financial development, foreign direct investment, natural resources, trade openness, energy consumption, and technological innovation. Additionally, articles were required to address the European Union, which was ensured by the inclusion of relevant keywords. Further terms included references to the Kuznets curve, regression techniques, and panel data analysis. These criteria, grounded in the literature review, resulted in

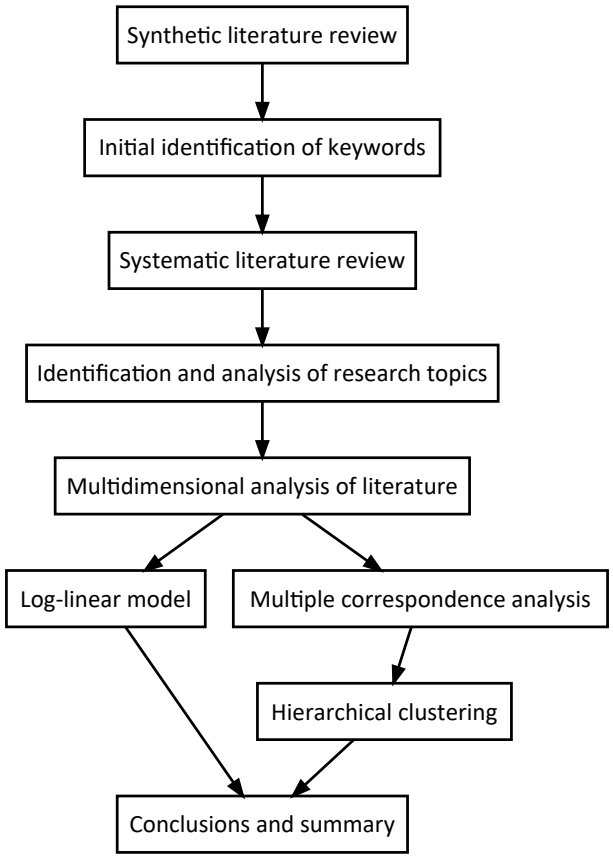

Figure 1. Review of the research process

Source: own elaboration.

the selection of 1548 unique articles that met the search requirements from 2014 to 2024, sourced from Google Scholar, Web of Science (WoS), and BASE.

The verification process was conducted based on several criteria, including authors' personal data, article title, journal title, and DOI number. In the library used, duplicates were removed at the bibliographic data import stage, ensuring that they were not included in the final dataset. In the second stage, the LitsearchR library (2019) was used for a naive keyword search. This library was chosen for its ability to automate and enhance the systematic review process, particularly in identifying relevant keywords with minimal bias. LitsearchR supports the automatic generation of Boolean search strings in up to 53 languages and offers stemming capabilities for English, making it highly versatile for multilingual datasets. It also facilitates bibliographic data extraction from sources like Google Scholar, which do not support native API access. The tool can cross-check search results against a set of known rele-

vant articles, providing performance metrics to ensure precision and recall in the retrieval process.

To extract research themes, text mining was conducted using the Rapid Automatic Keyword Extraction (RAKE) algorithm (Rose et al., 2010). RAKE was selected for its efficiency in identifying highly relevant keywords through co-occurrence analysis within the text. This algorithm requires minimal computational resources and complements other NLP models, leveraging open-source implementations.

With the assistance of LitsearchR, the retrieved articles were analysed, and the initial keywords were narrowed down to those with the highest relevance. A Document-Feature Matrix (DFM) was then constructed to create a co-occurrence map, which highlights how frequently and closely terms are linked, revealing underlying research themes and relationships. Node strengths within the map were optimised using change-point methods (2019), allowing for the identification of the most significant terms, while filtering out redundancies or less relevant data. To ensure precision, the "only shortest unique substrings" criterion was applied to further refine the keywords.

These keywords were thematically grouped and used to create a new query for further searches of bibliographic databases. The articles retrieved in the subsequent search were then compared with the previously selected articles, leading to the exclusion of 181 articles from the original dataset. Additional validation using fuzzy matching resulted in the removal of further 44 articles. This method, which measures textual similarity, helps identify duplicate entries or different versions of the same work, thereby enabling the detection of working papers later published in journals. Finally, a DFM matrix was constructed for further multidimensional analysis, and another matrix was created for additional analysis. The process of literature refinement and selection is summarized in the PRISMA flowchart (Figure 2), which provides a step-by-step visual representation of the screening and reduction stages.

In the third stage, key terms were extracted from the analysed publications using the LitsearchR package, based on co-occurrence networks and node strength, and then reduced accordingly. These terms and keywords were grouped thematically, creating a binary co-occurrence matrix for further analysis. The research methodology proposed by Bąk and Cheba (2023) was applied for the statistical examination of literature, with a focus on interactions between binary variables (Wiedermann & von Eye, 2020).

To determine relationships between research topics, a bootstrap χ^2 test was conducted to identify which topics co-occur in models examining the relationship between economic growth and CO_2 emissions in EU countries. Unlike the classical χ^2 test, which relies on a theoretical distribution of the test statistic, the bootstrap χ^2 test uses multiple re-samplings (bootstrapping) from the original data to empirically determine the distribution of χ^2 values. Both

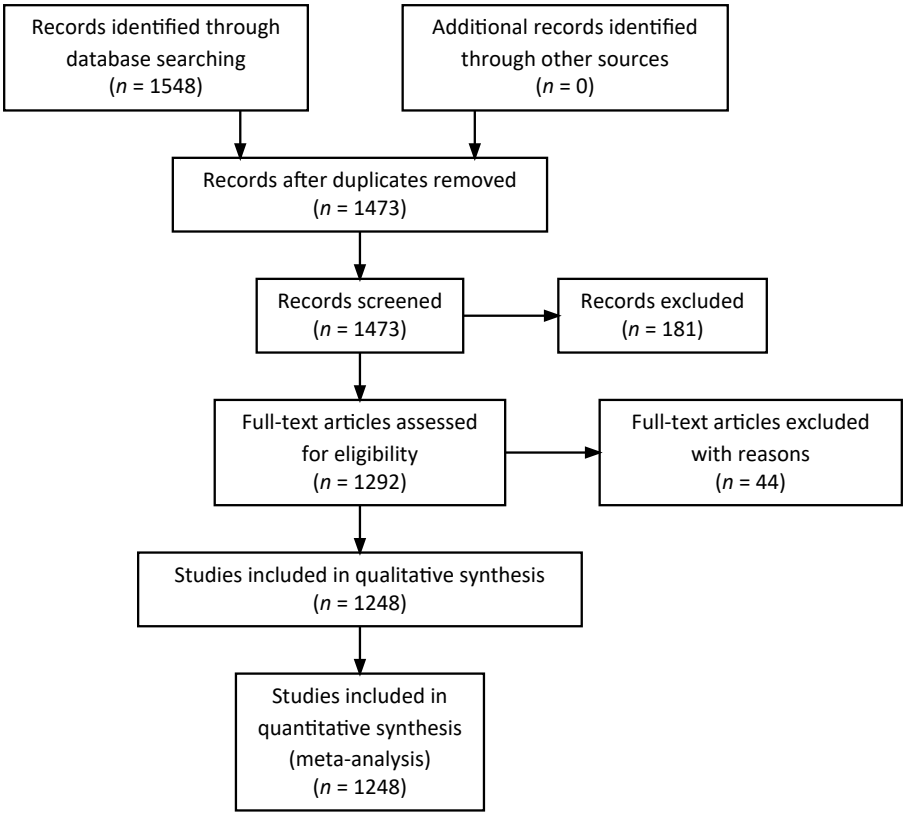

Figure 2. PRISMA flow diagram for the literature studied

Source: own elaboration.

approaches test the same null hypothesis (H_0)—that there is no dependence among the categorical variables—but the bootstrap method is especially advantageous for smaller datasets (Azen & Walker, 2021).

The literature discusses various methods for analysing interactions among categorical variables, including log-linear models, logistic regression, and generalised additive models (Agresti & Liu, 1999). The choice of model depends on the specific research context and data characteristics. Considering the objectives and the structure of the data, a log-linear model was employed to investigate interactions between topics, allowing for the modelling of categorical variables based on the Poisson distribution. The appropriate model was selected iteratively by reducing interaction levels and comparing the significance of modifications, using the gllm library. The general form of the log-linear model is as follows (Goodman, 1979):

$$\ln(Y) \sim XB + \epsilon \tag{1}$$

The detailed form of the log-linear model used in the study was defined as follows:

$$\ln\left(\hat{n}_{(ijkl\ldots)}\right) = \lambda_i^Y + \sum_{s=1}^{p}\lambda_j^{X_s} + \sum_{t=1}^{p}\lambda_{it}^{YX_t} + \sum_{u<v}\lambda_{uv}^{X_uX_v} + \ldots + \lambda_{i,j,k,\ldots}^{Y,X_1,X_2,\ldots,X_p} \quad (2)$$

where λ represents the model parameters in the following rows of interactions, and p is the number of independent variables.

In the next stage, key topics were grouped into main categories. Due to the numerous variables, dimensionality reduction was necessary. Multiple Correspondence Analysis (MCA) was applied to analyse relationships between categorical data (Hjellbrekke, 2018). MCA, which generalises Principal Component Analysis (PCA) for qualitative variables (Abdi & Williams, 2010), was performed using the FactoMineR package (Husson et al., 2017). The optimal MCA results were then subjected to hierarchical cluster analysis, enabling the identification of co-occurring research topics and the formation of distinct clusters. Clustering and visualisation were conducted using the FactorExtra library.

3. Systematic literature review

3.1. Keyword, thematic analysis and classification

In the first stage, a database of 1,548 publications indexed in the leading global databases was compiled. Based on titles, keywords, and abstracts, the key terms describing the relationships between CO_2 emissions and economic growth in European Union countries were identified. At this stage, the Litsearchr package was used twice. Initially, a naive search method was employed, allowing for the identification of the most significant keywords related to the links between CO_2 emissions and economic growth in the EU. The list of keywords used is presented in Table B1 in the Supplementary materials.

These keywords were then used to formulate a query aimed at narrowing down the search results, ultimately yielding a final set of 1,248 publications. Based on the keywords identified by the Litsearchr algorithm, a reduction was performed using the compute node strength method. As a result, only those keywords corresponding to nodes with high strength were retained. The term strength shift method was applied to pinpoint the jump points in the strength of individual terms. In this analysis, a midpoint was used to balance precision and brevity (presented in Figure B1 in the Supplementary materials).

In the second stage, based on the results from the naive search, selected keywords were further refined. The literature was then retrieved again using the narrowed keywords. After searching the literature and the selected keywords, a co-occurrence network of the chosen terms was visualised. Additionally, a document-feature matrix in binary form was created, which was used in subsequent stages of the study (Figure 3).

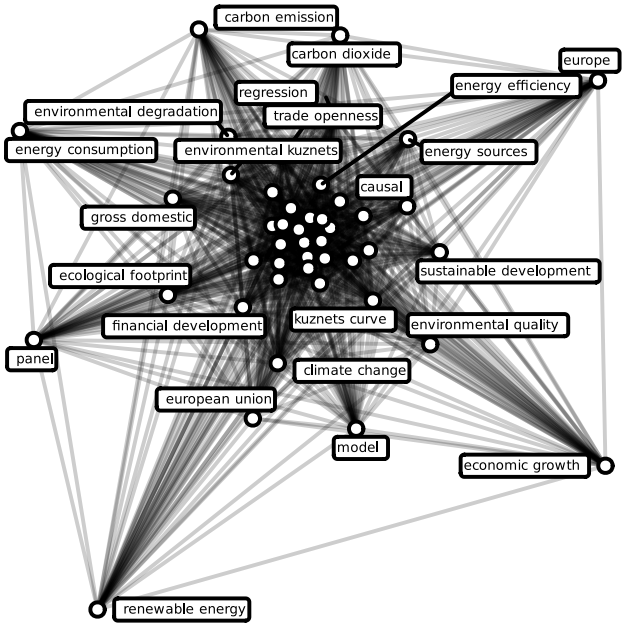

Figure 3. Nodal graph of main research terms

Source: own elaboration.

The analysis of the co-occurrence network and the document-feature matrix indicates that research on CO_2 emissions and economic growth in the European Union encompasses not only the direct relationship between these variables but also broader contexts, such as energy policy, technological development, and environmental progress. Based on the analysis of the co-occurrence network, the studied topics were grouped, as presented in Table B2 in the Supplementary materials. Furthermore, the analysis led to the formulation of the following conclusions:

1. **Central Concepts:** The highest concentration of connections is found around terms such as economic growth, carbon emission, environmental pollution, renewable energy, and sustainable development. This suggests that these topics are most frequently analysed together.
2. **Co-occurrences:** Topics such as panel causality, technological innovation, renewable energy, economic development, and energy consumption are

often linked to studies on CO_2 emissions and GDP. This suggests that the analysed research also considers the impact of technology, energy consumption, and sustainable development policies.

3. **Research Directions:** The connections between topics like carbon emissions, energy sources, non-renewable energy, and fossil fuels indicate numerous studies examining the relationships between CO_2 emissions and different types of energy, particularly renewable energy. The themes related to renewable and non-renewable energy dominated a significant number of studies.
4. **Topic Dispersion:** In addition to the main themes, the analysed studies also focused on less central concepts such as urbanization, climate change, ecological footprint, and environmental quality, indicating a broad range of factors considered in the research.

In the third stage, based on the data collected, a Boolean dependent variable *Y* was constructed. This variable indicates whether a scientific publication addresses issues related to models defining the relationship between eco-

Table 1. Characteristics of study variables

Variable	Name	Description
*X*1	Environmental Impact Factors	factors related to environmental degradation, pollution, environmental quality, climate change, ecological footprint
*X*2	Energy and Efficiency	variables related to energy, energy consumption, energy efficiency and energy transition
*X*3	Economic and Urban Development	factors related to economic development, urbanisation and financial development supporting economic growth
*X*4	Institutional and Sustainable Development	quality of institutions and sustainability
*X*5	Trade and Investment Openness	variables related to trade openness and foreign direct investment
*X*6	Natural Resources	fossil fuels, energy sources and resources
*X*7	Technological Innovation and Human Capital	technological innovation and human resources that support economic development and efficiency
*X*8	Econometric Methods and Models	variables related to statistical methods, regression analyses and causal models
*X*9	Renewable and Non-Renewable Energy	renewable and non-renewable energy and their impact on the economy and environment
Y	Dependent Variable	indicates whether a scientific publication addresses models of the relationship between economic growth and co_2 emissions in the european union (studies using a model or empirical evidence for the Kuznets curve)

Source: own elaboration.

nomic growth and CO_2 emissions in the European Union, particularly in the context of using a model or empirical evidence confirming the Kuznets curve. The construction of *Y* was based on content analysis (titles and abstracts) for the presence of specific keywords such as "nexus", "model", "regression", and "empirical evidence". If at least one of these keywords was identified, the publication was classified as meeting the criteria for variable *Y*.

Additionally, based on the analysis of the terms studied, independent binary variables were constructed, indicating whether a particular topic is addressed in the publication. These variables are presented in Table 1. All variables included in the analysis were selected based on their theoretical relevance and frequent occurrence in the scientific literature addressing this relationship. These variables reflect key research areas such as environmental impact, energy efficiency, economic development, trade openness, natural resources, technological innovation, and econometric methods. Each category was included to represent different dimensions of this multifaceted issue.

3.2. Relationship and log-linear analysis

To assess the significance of the relationships between the variables studied and the dependent variable *Y*, a χ^2 test was conducted, the results of which are presented in Table 2. Initially, variables such as *X*2, *X*4, *X*5, and *X*7 were included due to their theoretical relevance in studies on CO_2 emissions and economic growth. These variables represent key aspects often discussed in the literature, such as energy transition, institutional quality, trade liberalisation, and technological progress. However, the results of the χ^2 test indicated that these variables are not significantly associated with the dependent variable *Y* (*p*-value > 0.1).

The analysis suggests that only the main factors and, at most, second-order interactions effects should be included in the model, as these effects achieved statistical significance in both the χ^2 test of significance ($df = 15$, $\chi^2 = 95.18$, $p < 0.05$) and the Pearson test ($df = 15$, $\chi^2 = 81.24$, $p < 0.05$). Higher-order effects (third-order and above) were not significant, indicating that their inclusion would not provide additional benefits for the model.

Table 3 presents the results of marginal and partial association tests, showing how the variables (*X*1, *X*3, *X*6, *X*8, *X*9) relate to the dependent variable *Y* and how they interact with one another. In less technical terms, the log-linear model under consideration clarifies the impact of each variable on *Y*, while simultaneously accounting for their mutual interdependencies. The analysis indicates the significance of all interactions between *Y* and the *X* variables and suggested that the model should include the interactions: *X*1**X*3, *X*1**X*6, *X*1**X*8, *X*3**X*8, *X*3**X*9 and *X*8**X*9.

Table 2. Preliminary χ^2 test of the relationships between the variables *X* and *Y*

Variable	χ^2	*p*-value
*X*1	31.331	0.001
*X*2	2.666	0.121
*X*3	3.478	0.064
*X*4	1.536	0.233
*X*5	0.024	0.877
*X*6	3.523	0.071
*X*7	0.030	0.890
*X*8	8.666	0.003
*X*9	3.959	0.047

Source: own elaboration.

The full log-linear model is shown in Table B3 in the Supplementary materials, and detailed diagnostics of the model's fit to the data are presented in Figure B2 in the Supplementary materials. The points aligning along the straight line indicate that the model's predicted frequencies closely match the observed values, and the lack of marked deviations suggests that the residuals do not substantially violate the model's assumptions. The goodness-of-fit statistics—a likelihood ratio of 10.550 (p = 0.159) and Pearson's χ^2 of 11.430 (p = 0.131)—indicate that there is no basis for rejecting the hypothesis of

Table 3. Boundary and partial relationships tests

Interaction	Df	Partial relationships		Boundary relationships	
		χ^2	*p*-value	χ^2	*p*-value
*Y***X*1	1	30.799	0.000	30.048	0.000
*Y***X*3	1	3.546	0.060	2.981	0.082
*Y***X*6	1	4.875	0.027	6.277	0.012
*Y***X*8	1	9.457	0.002	6.731	0.009
*Y***X*9	1	4.410	0.036	3.615	0.057
*X*1**X*3	1	3.037	0.081	2.044	0.153
*X*1**X*6	1	2.744	0.098	4.019	0.045
*X*1**X*8	1	3.682	0.055	1.966	0.161
*X*1**X*9	1	0.000	0.993	0.122	0.727
*X*3**X*6	1	0.501	0.479	0.556	0.456
*X*3**X*8	1	2.879	0.090	3.203	0.073
*X*3**X*9	1	5.551	0.018	7.016	0.008
*X*6**X*8	1	0.776	0.378	1.149	0.284
*X*6**X*9	1	0.192	0.661	0.203	0.653
*X*8**X*9	1	16.276	0.000	16.141	0.000

Source: own elaboration.

a good fit (the model adequately explains the relationships among the analysed variables). Furthermore, the findings suggest that research focusing on the relationships among factors (*X*1, *X*3, *X*6, *X*8, *X*9) may yield more accurate conclusions and guide better decisions, particularly when multiple overlapping phenomena are examined simultaneously.

During the analysis, we also assessed whether higher-order interactions (third-order and beyond) provided significant contributions to the model. They proved insignificant, hence, only the key interactions were retained to keep the model as simple and transparent as possible, without compromising the accuracy of the relationships under investigation.

3.3. Multiple correspondence analysis

Finally, based on the model obtained, the analysis suggests that models explaining the relationships between CO_2 emissions and economic growth in the European Union are shaped by the following factors:

- Environmental Impact Factors,
- Economic and Urban Development,
- Natural Resources,
- Econometric Methods and Models,
- Renewable and Non-Renewable Energy.

Additionally, the following interactions were indicated by the analysis:

- Environmental Impact Factors and Economic and Urban Development,
- Environmental Impact Factors and Natural Resources,
- Environmental Impact Factors and Econometric Methods and Models,
- Economic and Urban Development and Econometric Methods and Models,
- Economic and Urban Development and Renewable and Non-Renewable Energy,
- Renewable and Non-Renewable Energy and Econometric Methods and Models.

The results of the cluster analysis confirm the association between the following research areas in the analysed literature:

- Environmental Impact Factors, Economic and Urban Development, Econometric Methods and Models, and Renewable and Non-Renewable Energy,
- Environmental Impact Factors, Econometric Methods and Models, and Renewable and Non-Renewable Energy,
- Economic and Urban Development and Renewable and Non-Renewable Energy,

– Environmental Impact Factors, Economic and Urban Development, and Renewable and Non-Renewable Energy.

To summarise this stage of the study, it can be stated that the main research axis of CO_2 emissions and economic growth in the European Union focuses on issues related to the use of renewable and non-renewable energy. These studies appear both independently and with regard to other factors, such as natural resources and economic development. Research on the relationship between economic growth and CO_2 emissions in EU countries is also linked to advanced econometric methods, including panel studies, quantile regressions, and ARDL models.

To further investigate the leading research areas in the analysed literature, a correspondence analysis was conducted. The data were divided into five categories, each assigned corresponding values. All categories with codes are included in Table 4.

Table 4. Categories used in multiple correspondence analysis

Category	Code	Description
Energy Sources (ES)	ES:1	no reference
	ES:2	non-renewable energy
	ES:3	renewable and non-renewable energy
State Quality and Sustainable Development (IQ)	IQ:1	no reference
	IQ:2	sustainable development
	IQ:3	institutional quality and sustainable development
Economic and Financial Development (EG)	EG:1	no reference
	EG:2	financial development
	EG:3	economic growth and financial development
Investments and Trade (IT)	IT:1	no reference
	IT:2	trade openness
	IT:3	foreign direct investment and trade openness
Environmental Pollution and Climate Change (PC)	PC:1	no reference
	PC:2	climate change
	PC:3	environmental pollution and climate change

Source: own elaboration.

The classification of articles based on these categories enabled the use of Multiple Correspondence Analysis (MCA) to explore the relationships between different thematic groups. Given the extensive size and dimension-

ality of the dataset (1248 × 14), the Burt matrix method was selected for its ability to manage large, high-dimensional categorical data. This approach is particularly well suited to situations where complex interrelationships between multiple categorical variables need to be examined. The Burt matrix allows for the efficient construction of contingency tables that facilitate the assessment of associations between categories, capturing intricate patterns and dependencies without oversimplifying the data.

To analyse the relationships between the categories, eigenvalues were derived from the MCA, and the optimal number of dimensions was determined using the elbow criterion. Based on the screen plot, three dimensions were identified as explaining 50.84% of the variance in the dataset (Table 5). While this value represents a substantial proportion of the variance, it is important to note that an explanation of 50% variance is often considered a reasonable threshold in social science research. In the context of large, multidimensional datasets, this level of explained variance provides sufficient explanatory power to uncover meaningful patterns and relationships, while at the same time allowing for the complexities inherent in the data (Hair et al., 2013). This balance ensures that the results remain robust, while avoiding overfitting or oversimplification of the model. Finally, a two-dimensional plot (Figure 4) of the coordinates for dimensions 2 and 3 was created to visualise the relationships and interdependencies among the thematic categories, offering a clear representation of the research themes derived from the MCA.

Table 5. Eigenvalues and variance explained by dimensions in multiple correspondence analysis

Dim	Eigenvalue	Percentage of variance	Cumulative percentage of variance
1	0.23	12.53	27.82
2	0.21	11.75	39.57
3	0.20	11.26	50.84
4	0.20	10.88	61.72
5	0.18	10.14	71.86
6	0.18	9.83	81.69
7	0.17	9.43	91.11
8	0.16	8.89	100.00

Notes: Dim: refers to the dimension identified by the MCA, Eigenvalue: measures the importance of each dimension in explaining the variance in the dataset.

Source: own elaboration.

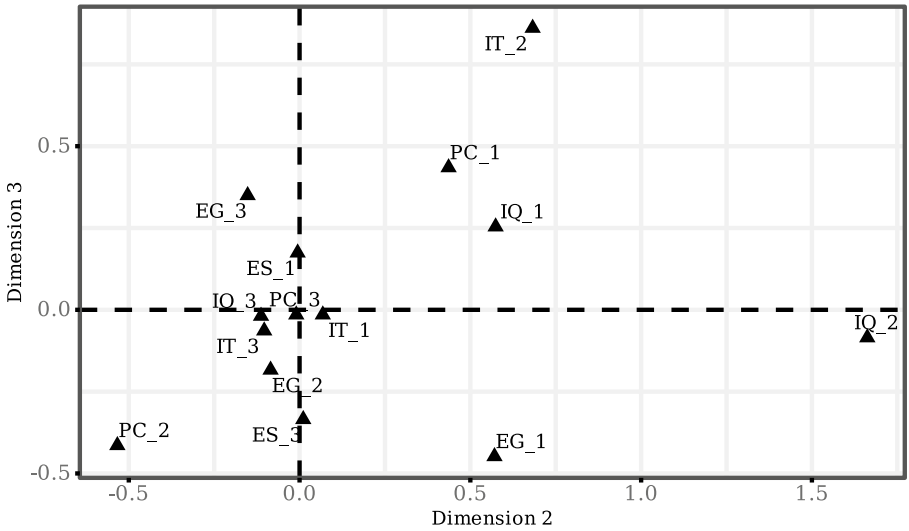

Figure 4. Distribution of variable categories in factor space (Dim 2 and Dim 3)

Notes: The figure covers five categories: ES (Energy Sources), IQ (State Quality and Sustainable Development), EG (Economic and Financial Development), IT (Investments and Trade), and PC (Environmental Pollution and Climate Change). The numeric indices (1, 2, 3) represent subcategories.

Source: own elaboration.

The resulting plot indicates that topics related to EG : 2 (financial development) and ES : 3 (non-renewable and renewable energy) are often considered together. Research in these areas is frequently combined with topics such as IT : 3 (foreign direct investment and trade openness) and PC : 3 (environmental pollution and climate change). The influence of renewable energy, specifically PC : 2 (climate change), is often considered separately. Topics such as IQ : 2 (sustainable development) and IT : 2 (trade openness) are typically considered independently, as their points are furthest from the centre of the plot. The distance of ES : 1 (energy sources) from the other items suggests limited overlap with the other topics. This indicates that research in this area focuses on the general impact of energy consumption on economic growth and CO_2 emissions, without a detailed distinction between renewable and non-renewable energy sources.

To summarise the relationships in the topics analysed here, a dendrogram was created. Based on the results obtained from the MCA, clustering was performed using three dimensions, with Euclidean distance and a modified Ward method. The results of the analysis are presented in Figure 5. Analysis of the dendrogram reveals three main clusters within the research themes. Group I includes studies (ES : 3) related to renewable and non-renewable energy, which co-occur with topics related to sustainable development (IQ : 2).

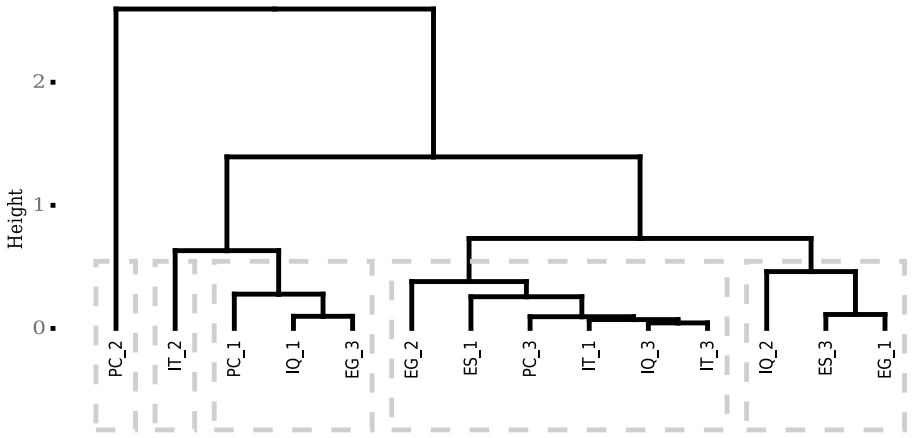

Figure 5. Classification based on clusters for the thematic categorisations studied

Source: own elaboration.

Group II consists of research linking financial development (EG : 2) with environmental pollution and climate change (PC : 3), as well as factors such as international trade and foreign direct investment (IT : 3), and institutional quality and sustainable development (IQ : 3). Some of these studies do not distinguish between renewable and non-renewable energy. Group III comprises studies focusing on economic growth and financial development (EG : 3) but not addressing climate change and environmental pollution (PC : 1) alongside sustainable development (IQ : 1). These studies are thematically connected to issues of trade openness (IT : 2). Nonetheless, all the studies are related to the broader theme of climate change (PC : 3).

4. Discussion

A systematic and synthetic analysis of the literature, as well as a log-linear model, shows that economic development factors and the use of renewable and non-renewable energy sources are particularly important in the study of the EKC in EU countries. The co-occurrence of these factors indicates that they are key in modelling the relationship between GDP and CO_2 emissions (Lau et al., 2023; Shahbaz & Sinha, 2019). In turn, the MCA study identified several clear research directions, focusing on assessing energy use (renewable and non-renewable) in combination with sustainable development, financial development and commercial openness to reduce CO_2 emissions in EU countries (Barros & Martínez-Zarzoso, 2022; Lau et al., 2023).

The cluster classification further distinguished groups combining diverse thematic areas (e.g., financial development and trade with climate issues, and climate change and economic development with specific environmental aspects), confirming earlier observations about the cross-fertilisation of different scientific fields in EKC research (Hasanov et al., 2021; Leal & Marques, 2022). Considering these findings, it is apparent that the key area for research into the relationship between CO_2 emissions and economic growth in the EU remains the topic of energy (RES vs. fossil fuels), which coincides with many studies highlighting the impact of energy consumption patterns on emissions intensity and climate policy orientations (Anwar et al., 2022; Sarkodie & Strezov, 2019).

The quality of institutions, international trade and financial development are secondary themes; however, their role is sometimes classified differently by different authors or only hinted at (Bąk & Cheba, 2023; Barros & Martínez-Zarzoso, 2022). The results of empirical studies lend credence to the thesis that these variables interact with each other, which, given the different methodologies, explains the multiplicity and sometimes contradictory conclusions about the properties of the EKC (Kaika & Zervas, 2013; Leal & Marques, 2022; Sovacool et al., 2021). The results obtained indicate that EKC analysis requires not only looking at the relationship between GDP growth and emissions, but also considering a combination of energy, socio-economic and methodological factors (Bąk & Cheba, 2023; Mardani et al., 2019; Shahbaz & Sinha, 2019).

Conclusions

This study aimed to identify key research areas concerning the link between GDP and CO_2 emissions in research on EU countries with a particular focus on the EKC hypothesis. A review of theoretical concepts and empirical studies indicates that the relationship between the economy and the environment occupies an important place in the field of economic science. However, this study shows that there are still many issues that have not been sufficiently clarified, some concepts are controversial, and others are in constant evolution.

Empirical and theoretical concepts are evolving with new variables and methodologies; despite a significant number of studies, new articles are still emerging that introduce additional factors to better understand the relationship between GDP and CO_2 emissions. The analysis conducted reveals that studies in the area of EKC take into account numerous additional factors such as innovation, legislation, geography, production structure and urbanisation. The individual studies also apply geographical differentiation, taking account of different regions and countries according to data availability. However,

there is less research in the area of environment-economy relations focusing specifically on EU countries than there is on developing countries from the African and Asian region (Anwar et al., 2022; Lau et al., 2023).

The results of the log-linear and MCA analyses indicate that EKC research on the EU concentrates on the relationship between GDP and CO_2, primarily focusing on factors such as energy, financial development, foreign investment, and natural resources, all of which are closely tied to institutional quality, sustainability, and climate change. Among the analysed topics, the most attention is given to the impact of renewable energy on CO_2 emissions, which largely reflects the EU's climate and energy objectives.

The study also indicates that many research topics are closely linked to specific econometric methods and models, which are essential tools for studying CO_2-GDP relationships. These methods are used in particular for analysing how renewable and non-renewable energy use, and environmental factors affect CO_2 emissions in the EU. Common approaches include the autoregressive distributed lag (ARDL) regression model (OLS), quantile regression (QR) and various causality tests (Granger and Toda-Yamamoto).

The study identifies research gaps in the existing literature on the GDP--CO_2 relationship. Firstly, individual country analyses should be prioritized over large aggregates, considering country-specific factors in panel studies for consistency. Secondly, more research is needed on the impact of various pollutants on economic growth, as most studies focus solely on CO_2. Thirdly, sectoral studies on the EKC for the EU remain limited, particularly regarding transport and agriculture, despite some focus on energy and industry. Such research is crucial for effective emission reduction strategies. Lastly, there is a significant gap in examining technological progress and trade openness, especially concerning pollution exports.

The study highlights that the link between economic growth and emissions in the EU remains insufficiently explored. Therefore, increased funding is needed for research on climate policy's economic impact, along with in-depth sectoral analyses, particularly in transport and agriculture. Collecting long-term, detailed data at national and EU levels is also crucial to support new research and theories for informed economic and climate policy decisions.

This study has several limitations. First, the analysis relied on articles from major databases (2014–2024) using specific keywords, which may have led to omissions. The reviewed literature employs diverse methods and control variables, leading to discrepancies and limiting universal conclusions. While focused on the EU, most studies use panel data with common assumptions, potentially overlooking country-specific factors like economic development or energy structure.

Future research on the GDP-CO_2 relationship in EU countries should address research gaps by applying modern econometric techniques, including convergence and longitudinal effects, and using longer time series for deeper

insight into pollution reduction. It should also consider shocks like the war in Ukraine and new US policies. Additionally, studies on the EKC and systematic reviews should explore non-traditional methodologies, such as Bayesian inference, deep learning, and AI experiments.

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Energy mix and its implications on the Vietnamese economy by 2030: A CGE analysis using GTAP-E-Power

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Abstract

This study uses the GTAP-E-Power model to examine the economic and environmental implications of transitioning to different energy generation mixes in Vietnam by 2030. Three scenarios were considered for that year: (1) low-coal and high-gas, (2) low-coal and high-renewables, and (3) high-coal. Scenario 2 emerges as the most balanced approach, resulting in a 1.02% GDP decline and a 0.78% increase in CO_2 emissions. In this scenario, the electronics sector grows slightly (+0.3%), while metals (–3.1%) and chemical products (–1.0%) experience moderate declines. In terms of exports, Scenario 2 gives rise to an increase in the trade balance (151 million USD) and a modest gain in exports to China (+0.46%), Japan (+0.37%), Korea (+0.33%), and Western Europe (+0.35%). Across all three scenarios, the output of the electronics industry shows sensitivity to energy mix changes, while the coal mining sector seems to be resilient to changing the energy mix.

Keywords

- GTAP-E-Power
- CGE
- Vietnam
- energy mix
- renewable energy

JEL codes: C68, O13, Q43

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Introduction

The composition of electricity generation, also termed the energy mix, plays an important role in determining a country's economic and environmental outcomes (Adebayo et al., 2024). A fossil-heavy mix provides a cheap and stable energy supply but increases dependence on fossil fuel prices, while a renewable-focused mix enhances energy security but requires high capital investment (Marques et al., 2019). Additionally, an energy mix dependent on imports can affect growth through trade imbalances and price volatility (Murshed, 2021). In terms of environmental impact, fossil-heavy electricity generation is the largest contributor to global emissions (IEA, 2019). Therefore, a transition to low-carbon energy is essential to meet climate targets and align with the Paris Agreement (UNFCCC, 2015). This has been supported by a great deal of research highlighting the negative relationship between the share of renewable energy resulting from phasing out coal power and emissions from the electricity sector (Raza et al., 2025).

As a developing country, Vietnam presents an interesting case for studying the economic implications of energy transition. The country has witnessed significant economic growth, with an average annual GDP growth rate of 6.5% between 2000 and 2019 (World Bank, 2021). However, this growth has also led to increased energy consumption and greenhouse gas emissions. In 2019, Vietnam's total greenhouse gas emissions reached 364.5 million metric tons of CO_2 equivalent, with the energy sector contributing 65.8% of the total emissions (Ministry of Natural Resources and Environment, 2020). Recognizing these environmental consequences, Vietnam updated its Nationally Determined Contribution (NDC) under the Paris Agreement in 2022, committing to a 15.8% reduction in greenhouse gas emissions by 2030 compared to the business-as-usual scenario, with the potential to increase this reduction to 43.5% with international support (UNFCCC, 2022). The government also identified shifting the energy mix towards low-carbon energy as a key strategy for Vietnam in fulfilling the NDC commitments (Handayani et al., 2022). This strategy has already been proved to be potentially effective in some empirical studies in the Vietnamese context. For example, using wavelet analysis, Le (2022) analysed the time-varying nature of relationships between non-renewable and renewable energy consumption, economic growth, and CO_2 emissions in Vietnam and found that the relationship between renewable energy and CO_2 emissions is more pronounced in the period from 2003 onwards. The study also pointed out that although consumption of non-renewables is important in promoting early economic development, the magnitude of this relationship is diminishing over time, and its impact on CO_2 emissions tended to grow from 2009 onwards. This finding is further corroborated by V. C. T. Nguyen and Le (2022), who used

an Error Correction Model to show a long-term positive but short-term negative relationship between consumption of non-renewables and growth. Another interesting mechanism in the Vietnamese renewable-emission nexus has been proposed by Hung (2023), who offered evidence on the role of remittances in accelerating CO_2 emissions by using wavelet analysis. The study found that remittances significantly contribute to elevated CO_2 emissions in the short- and medium term, mostly via investment in non-renewable energy projects, and that renewable energy and CO_2 emissions actually have bidirectional causality, suggesting that financial moderation of remittances focused on environmentally friendly projects might have impacts on the long-term expansion of renewables. Other approaches that can be considered for Vietnam to promote the energy shift include leveraging international climate funds, joining carbon credit markets, and streamlining foreign direct investment (FDI). Participation in global initiatives can facilitate financial support for developing countries to scale up clean energy projects. In addition, joining international carbon credit markets, following Article 6 of the Paris Agreement, allows Vietnam to sell carbon credits derived from renewable projects, which in turn provides Vietnam with the necessary climate finance and technology support to further expand its renewable share. Streamlining FDI investments towards green projects can contribute to technology transfer, infrastructure development, and project financing, ensuring a more sustainable and cost-effective energy transition. These approaches have been proved to be effective ways to promote green energy transition (Buchner et al., 2023; Huang et al., 2023; Oladapo et al., 2024).

However, the transition to a low-carbon power system also carries economic implications and difficulties, including asset risk for coal power plants, the need for transmission and renewable generation investments, and the potential impacts on the fossil fuel industry (IRENA, 2017, 2018; Spencer et al., 2018). To be specific, high initial investment in renewable infrastructure, grid integration and technology can pose a significant challenge for developing countries like Vietnam, where access to affordable financing and long-term capital remains limited. In addition, numerous factors, such as policy uncertainty, concerns over power purchase agreements, grid infrastructure reliability and market volatility, can also discourage investment in renewable power. Vietnam, in particular, has made some efforts to mitigate these financial risks by introducing feed-in tariffs (FITs) for wind and solar projects and has already achieved some success in expanding these energy types. Other measures taken by developed nations to mitigate such risks and ensure a stable investment environment for renewable energy development include auction-based pricing mechanisms, green bonds, and financial guarantees to attract both domestic and foreign capital.

In this study, we evaluate the economic implications of transitioning to different energy mixes in Vietnam. To achieve this objective, we first analysed the

Vietnamese government's master plans for energy development to determine optimistic and pessimistic energy generation mixes by 2030. We then simulated these scenarios in a computable general equilibrium (CGE) framework to reveal important economic indicators and welfare relative to the baseline scenario in 2030, where no power transition policies are implemented. The results of this analysis are expected to provide valuable insights and recommendations for policymakers, stakeholders, and researchers in Vietnam, justifying the transition to a renewable energy mix as a feasible solution for fulfilling NDC commitments.

1. Methodology

1.1. The GTAP-E-Power model

To examine the implications of different energy mixes on the Vietnamese economy, we used the GTAP-E-Power model. GTAP-E-Power is a type of applied CGE model commonly used in ex-ante policy analysis, especially when it comes to environmental and energy issues. Being a CGE model, the GTAP-E-Power model consists of a system of simultaneous equations grounded in economic theory that describes the behaviors of economic agents in the economy and is solved following general equilibrium theory (supply equals demand in all goods and factor markets). The model consists of multiple regions, all linked via export and import equations. In each region, a hypothetical regional household collects all income from one private household, one government, and many representative firms, each representing one industry. The collected income is then redistributed among the private household, the government, and investment so that the utility (in Cobb-Douglas form) of these three entities is maximised. The representative firm operates under a cost-minimising condition and utilises numerous inputs following a constant elasticity of substitution (CES) production structure with many levels, also called nests, to produce an output, as illustrated in Figure 1. In the conventional CES production function with one level, all inputs are assumed to share one elasticity of substitution (σ). In the nested CES production function, some inputs can have an elasticity of substitution that is different from that of some other inputs, allowing for a better representation of the functional role of inputs in production.

The GTAP-E-Power model is a combination of GTAP-E, the environment-energy extension of the standard Global Trade Analysis Project (GTAP) model, and GTAP-Power, the electricity-detailed extension of the standard GTAP

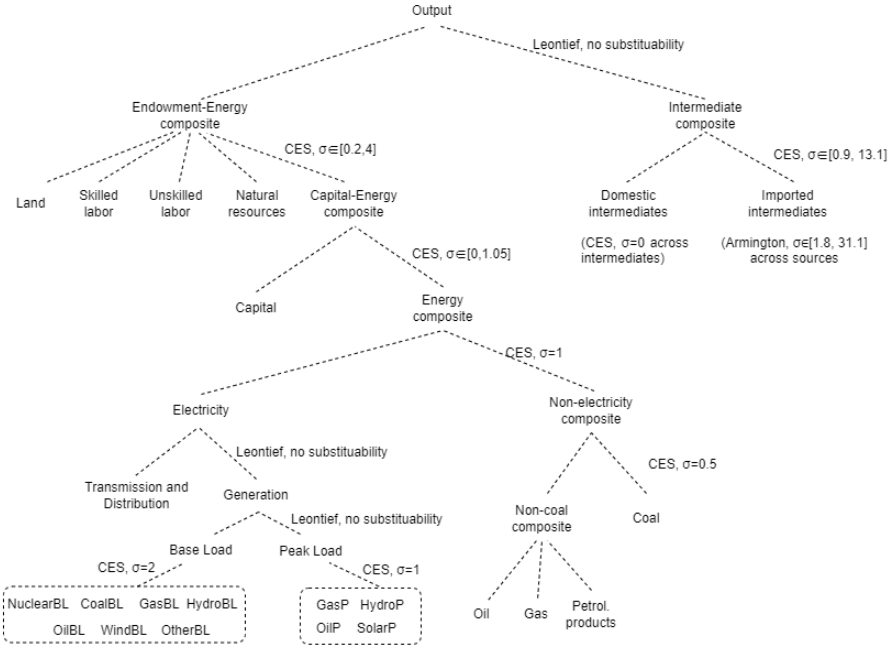

Figure 1. Production structure in GTAP-E-Power model

Source: adapted from the GTAP-E-Power model and (Peters, 2016).

model. In the GTAP-E model, the production structure adds energy as a new production factor (in addition to capital, labour, and intermediates), and integrates it with capital to form a capital-energy composite factor. The energy commodity nest is further broken down into smaller nests formed by electricity, coal, crude oil, gas, and petroleum products. This nested structure of the GTAP-E-Power model allows sectors to substitute between intermediate inputs, fossil fuels, energy types, and endowments. In addition, separating energy into different sub-commodities allows for the calculation of emission intensity and total emission resulting from the usage of coal, crude oil, gas, and petroleum products, the four primary carbon-emitting commodities. In the GTAP-Power model, Peters (2015) further broke down the electricity commodity into the transmission and distribution commodity and the generation commodity. The generation commodity is formed by a base-load nest and a peak-load generation nest. Baseload electricity covers generation technologies characterized by high efficiency but substantial investment costs, and which cannot adjust quickly to fluctuations in demand. On the contrary, peak load technologies involve less investment outlay but with lower efficiency, and designed to respond quickly to demand fluctuations. The distinction between base- and peak-load generation reflects the unique properties of the electricity

Table 1. Region and sectoral aggregation of the GTAP-E-Power model

Regions		Sectors	
1	Vietnam	1	Agriculture
2	China	2	Coal mining
3	Korea	3	Crude oil
4	Japan	4	Gas extraction & distribution
5	India	5	Extraction of other minerals
6	The US	6	Processed food
7	Western Europe	7	Refined oil products
8	Rest of the world	8	Textiles & wearing apparel
		9	Chemical products
		10	Non-metallic minerals
		11	Metals
		12	Electronics & electrical equipment
		13	Machinery & other equipment
		14	Vehicles and parts & other transport equipment
		15	Other industries
		16	Transmission & distribution of electricity
		17	Nuclear baseload
		18	Coal baseload
		19	Gas baseload
		20	Wind baseload
		21	Hydro baseload
		22	Oil baseload
		23	Other baseload
		24	Gas peakload
		25	Hydro peakload
		26	Oil peakload
		27	Solar peakload
		28	Services

Source: adapted from (Aguiar et al., 2022).

market, where power demand can fluctuate, and different generation technologies serve complementary roles to satisfy the electricity demand. Later, Peters (2016) unified the features in the production nest of both extensions into a single model of GTAP-E-Power. Table 1 presents sectors and regions included in the GTAP-E-Power model used in this study.

The data for the GTAP-E-Power model were aggregated from the GTAP database version 11, with the base year of 2017, which covers 160 regions and 65 sectors. 2017 is the most recent year in which GTAP-E-Power database updates were available at the time of conducting this study. It also represents a pre-pandemic state, where all economic structures and transactions are normal and not affected by COVID-19 pandemic restrictions. We also supplemented the model with capital-energy substitution elasticities that were econometrically estimated in our previous study (D. C. Nguyen & Ko, 2024).

1.2. Scenarios

The scenarios employed in our study were designed as follows. We first projected the aggregated GTAP-E-Power database to the year 2030 by shocking capital stock, labour force, population, and GDP of all regions to the year 2030 under a modified closure, where GDP is set as exogenous and endowment productivity as endogenous. The 2017–2030 growth rates are calculated using data from World Bank Indicators (for the 2017–2023 period) and the forecast from the SSP2 scenario of Fontagné et al. (2022) (for the 2023–2030 period). The use of projection based on real data for the 2017–2023 period allows the model to capture pandemic-induced abnormalities in growth. After conducting the 2017–2030 projection, the closure was reverted to the standard closure, and productivity changes were used in place of GDP projections to form the baseline scenario.

Using this baseline, we developed three policy scenarios with different electricity output compositions coming from generation technologies in Vietnam, as summarised in Table 2. The generation mix was specified by adjusting the output of electricity sectors under a modified closure, where the output of the shocked sector was set as exogenous and swapped with its technical productivity. In the first scenario—termed low coal, high gas—in addition to the baseline projection shocks, we applied appropriate shocks to outputs of gas-fired, coal-fired, and hydroelectricity sectors in the Vietnam region so that the simulated energy mix approximates the 2030 target mix described in Vietnam's newest energy plan: Decision 500 (Prime Minister of Vietnam, 2023). Signed by the Prime Minister of Vietnam in May 2023, Decision 500 describes Vietnam's national electricity development plan for the period 2021–

Table 2. Simulated energy mixes for Vietnam in the GTAP-E-Power model

Scenario	Simulated energy mixes				Reference energy mixes	
	Baseline (%)	Scenario 1 low-coal high-gas (%)	Scenario 2 low-coal high-renewables (%)	Scenario 3 high-coal (%)	Decision 500–2030 target mix (%)	Decision 428–2030 target mix (%)
Renewables	57.7	55.6	60.4	42.2	49.8	40.9
Coal-fired	29.5	24.9	26.8	41.9	25.7	42.6
Gas-fired	12.3	19.1	12.2	14.4	20.7	14.7
Oil-fired	0.5	0.2	0.5	0.0	0.0	0.0
Others	0.1	0.2	0.1	1.5	3.8	1.8

Source: calculated from GTAP-E-Power model results and policy documents.

2030 with a vision to 2050 and serves as one of the key policy measures to help accomplish the ambitious NDC submitted in 2022. The decision sets out targets for the shares of different generation sources in the country's electricity mix by 2030, with a focus on more renewables and gas.

The second scenario—termed low-coal, high-renewables—is similar to the first scenario except that we only applied a shock to the output of the coal-fired electricity sector to resemble Decision 500's decommission pathway for coal-fired power plants in Vietnam to 2030 and allowed outputs of non-coal electricity sectors to be endogenously determined. This resulted in a scenario where renewable energy, mainly comprising hydroelectricity, predominates over other generation sources. The rationale behind this second scenario is to assess how the Vietnamese economy responds to the aggressive phasing-out of coal power, while allowing market forces to determine the mix of replacement generation.

In the third scenario—termed high-coal—baseline shocks were applied to the model and a large shock to the output of the Vietnamese coal-fired power sector in order that the final energy mix resembles that described in Decision 428 (Prime Minister of Vietnam, 2016). Decision 428, issued in March 2016, approved the Revised National Power Development Master Plan for the 2011–2020 Period with a Vision to 2030, focusing on expansion of coal-fired power generation by 2030. Its target is for coal power capacity to reach over 55 GW by 2030, accounting for 42.6% of the total installed capacity. However, in 2023 it was superseded by Decision 500.

2. Results and discussion

2.1. Simulated changes in Vietnamese sectoral outputs

Shifting the energy mix toward a less carbon-intensive composition is expected to reduce the demand for fuel commodities and possibly lower output in sectors whose input composition is heavily dependent on fossil-based energy, and vice versa (Sikder et al., 2019). Table 3 presents the impact of different energy mixes on the sectoral outputs of Vietnam in 2030. In Scenario 1, we restricted the output growth of Vietnam's renewable, coal, and oil energy sectors to achieve the target composition. As a result, the output of gas and other energy sources was raised to compensate for the loss in electricity output. The gas power sector's output increased by 66.9% compared to the baseline. This increase is primarily attributable to the baseload gas power sector, where a change of approximately 293% was registered. Strikingly, although the output of the coal power sector was forced to remain almost unchanged compared to the 2017 baseline, we found that the coal power sector actually consumed around 101% more input (e.g., coal, electricity, or capital). Under a production function with constant return to scale and endogenous technical change, this can only mean that output-augmenting technical change was significantly lowered (–69% compared to the baseline). Our findings on the increased input consumption in the coal power sector, despite unchanged output, align with the observations of Cui et al. (2019), who noted that policy constraints on coal power plants can lead to operational inefficiencies. In our model, the reduced productivity of the coal power sector could be attributed to rising coal prices (4.17% compared to the baseline). Typically, the increase in coal prices would have led to higher input costs for the coal power industry, and the sector, facing rising costs, would have attempted to adjust input usage or production levels to minimise costs. However, because a fixed output constraint was imposed on coal power and because the electricity generation sectors are not allowed to substitute inputs in the GTAP-E-Power model, the coal power sector is unable to reduce its coal consumption. As a result, it must compensate by using additional input—including electricity and capital—to maintain the same level of output, leading to production inefficiency. The increased use of coal, despite its higher price, is part of this overall efficiency reduction, where more input is required to produce the same output.

As the largest consumer of coal in Vietnam, the coal power sector's increased coal consumption has also led to higher output in the domestic coal mining sector. Specifically, the energy mix policy effected a 30.2% rise in coal mining output in Scenario 1 relative to the baseline. This is due to the aforementioned coal price rise, which incentivises the sector to produce more coal,

Table 3. Impact of changes in energy mix on the sectoral output of Vietnam relative to the 2030 baseline (US$ million)

	Scenario 1	Scenario 2	Scenario 3
Agriculture	–749 (–0.8%)	–27 (0.0%)	–248 (–0.3%)
Coal mining	818 (30.2%)	24 (0.9%)	1,099 (40.6%)
Crude oil	–133 (–3.2%)	6 (0.1%)	–147 (–3.5%)
Gas extraction & distribution	–186 (–9.6%)	–2 (–0.1%)	79 (4.1%)
Extraction of other minerals	75 (2.2%)	–49 (–1.4%)	268 (7.9%)
Processed food	–532 (–1.1%)	–142 (–0.3%)	337 (0.7%)
Refined oil products	–686 (–1.8%)	104 (–0.1%)	–1,194 (0.4%)
Textiles & wearing apparel	–981 (–14.2%)	–60 (2.1%)	198 (–24.7%)
Chemical products	–923 (–2.2%)	–412 (–1.0%)	–724 (–1.7%)
Non-metallic minerals	–98 (–0.6%)	–351 (–2.2%)	1,453 (9.0%)
Metals	–4,640 (–12.4%)	–1,142 (–3.1%)	1,984 (5.3%)
Electronics & electrical equipment	–36,700 (–24.2%)	470 (0.3%)	–16,038 (–10.6%)
Machinery & other equipment	–497 (–6.4%)	–85 (–1.1%)	20 (0.3%)
Vehicles, parts & other transport equipment	1,083 (6.6%)	–246 (–1.5%)	2,087 (12.8%)
Other industries	47 (0.1%)	–632 (–0.8%)	1,643 (2.0%)
Transmission & distribution of electricity	894 (12.3%)	–349 (–4.8%)	1,539 (21.1%)
Renewable power	–294 (–2.7%)	365 (3.3%)	–2,503 (–22.8%)
Coal-fired power	–961 (–17.1%)	–736 (–13.1%)	3,771 (66.9%)

table 3 continued

	Scenario 1	**Scenario 2**	**Scenario 3**
Gas-fired power	1,594 (66.9%)	–61 (–2.6%)	826 (34.7%)
Oil-fired power	–75 (–80.7%)	–1 (–1.1%)	–104 (–112.4%)
Other power	29 (236.7%)	0 (0.5%)	360 (2983.2%)
Services	–5,339 (–2.8%)	–1,048 (–0.5%)	–3,868 (–2.0%)

Source: calculated from the GTAP-E-Power model result.

hence higher output. Similar patterns have been observed in other contexts, such as China and India, where energy mix policies emphasising coal-fired power generation have led to significant increases in coal output (IEA, 2020; Ministry of Coal, 2021). The new energy mix reduced output in the electronics and electrical equipment sector by 24.2%, with demand for energy in this sector increasing by approximately 20%. However, this was overshadowed by a decline in capital use (–46%) and intermediate input (–21.5%). On the other hand, we found that the shift in the energy mix led to the reallocation of capital towards sectors more directly involved in the new energy infrastructure. Indeed, we established that significant capital endowments were allocated to major sectors of the Vietnam economy to accommodate the forced energy shift, including the coal mining sector (204%), coal power (102%), baseload hydropower (117%), and baseload gas power (282%). Similar situations were also observed in textiles and apparel, metals and machinery, and other equipment sectors. This observation is consistent with Khalil and Strobel (2023), who found that climate policy can induce a capital shift from carbon-intensive sectors to sectors with lower emission intensity.

In Scenario 2, where only the output of the coal-fired power sector was restricted, the impacts appear to be milder across most sectors of the Vietnamese economy compared to Scenario 1, thus suggesting that a shift toward a more renewable-focused energy mix might lead to less economic disruption than a more gas-heavy composition. In the power generation sector, constraining the growth of coal-fired power shifted the composition towards renewables, with renewable power registering growth of 3.3%. Gas-fired and oil-fired power show smaller decreases of 2.6% and 1.1%, respectively. Interestingly, despite the decrease in coal-fired power, the coal mining sector registered a slight increase of 0.9% in output. Although the coal power sector does not consume significantly more coal compared to the baseline, other

sectors, such as the coal mining sector itself, the agriculture sector, and the electronics and electrical equipment, increased their coal usage (4%, 2%, and 2%, respectively) to substitute for smaller increases in capital endowments. These findings carry two main implications. First, simply decommissioning the coal power sector without imposing restrictions on other power sources is unlikely to bring about significant changes in the outputs of upstream extractive sectors. Second, these sectors may demonstrate some resilience or adaptability in response to changing energy policies in the form of the ability to shift production towards export markets or to change their input composition flexibly. With specific regard to Vietnam's coal mining sector, the substitution elasticity between production factors is approximately 4, which is much higher than those of other sectors, such as oil extraction (0.4), gas extraction (0.04), and manufacturing industries (1.26). This allows the coal mining sector to maintain or even slightly increase its output, despite reduced demand from the coal-fired power sector.

The electronics and electrical equipment sector in Scenario 2 registered an increase in output of 0.3% relative to the baseline. Examining the change in demand in this sector reveals that demand for energy in the sector dropped by –4.9%, with demand for capital increasing by 1.2% as a result of the coal power reduction policy. This contrasts with Scenario 1, where significant capital was reallocated from non-energy to energy sectors. For vehicles, parts, and other transport equipment, we note the opposite shift from positive (6.6%) to negative outcomes (–1.5%) when moving from Scenarios 1 to 2. This differing impact can be attributed to the fact that Vietnam's vehicles sector has far lower export levels compared to its electronics and electrical equipment sector, making it more reliant on and thus sensitive to domestic demand. This could be easily altered by domestic energy shifts. Indeed, comparing demand for vehicles and vehicle parts in the two scenarios reveals that the aggressive energy shift in Scenario 1 led to significant changes in demand for vehicle commodities in energy generation sectors, including coal baseload (101%), gas baseload (282%) and hydro baseload (117%). Meanwhile, in Scenario 2, the coal baseload, gas baseload, and hydro baseload sectors only required 0.94%, 7.18%, and 2.96% more vehicle commodities relative to the baseline, respectively.

In Scenario 3, where coal-fired power predominates over other generation technologies, in addition to obvious changes in the power sectors, we noted a significant, positive impact of coal power-promoting policy on the output of the coal mining (40.6%), mineral extraction (7.9%), non-metallic minerals (9%), metals (5.3%), vehicles (12.8%) and electricity transmission (21%) sectors. It is easy to justify the coal mining sector's sharply elevated output in response to the policy shock because Scenario 3 mainly focused on expanding the share of coal power in the energy mix. As a result, this mining sector has to raise its production to provide coal for power generation. For the non-me-

tallic minerals sector, the sector with the second highest coal consumption, the policy caused the demand for energy commodities in this sector to rise by 21.89%. However, this was compensated by a reduction in capital demand by –13.37%, which was reallocated to facilitate the expansion of coal energy. The phenomenon of capital divestment is not unique to the non-metallic minerals sector. In fact, we found that crude oil extraction, mineral extraction, food processing, oil refinery, chemical, electronics, machinery, and equipment sectors all suffered from a reduction in capital, ranging from –7.6% to –26.5%. Such significant capital reallocation observed in this scenario raises concerns about long-term economic sustainability and diversification. While the expansion of coal-fired power drives growth in related heavy industries, the capital divestment from crucial industries like electronics, machinery, and chemicals could potentially hinder Vietnam's ability to move up the global value chain and diminish its ability to innovate and compete internationally (Nguyen et al., 2020). Moreover, the heavy reliance on coal power in this scenario may pose significant challenges to Vietnam's ability to meet its international climate commitments and could expose the country to future economic risks as global markets increasingly prioritise low-carbon goods and services (Ha-Duong et al., 2016).

2.2. Simulated changes in exports, GDP, welfare, and emissions

Table 4 presents the impact of changes in Vietnam's energy mix on the export values of important commodities to major trading partners under Scenarios 1, 2, and 3, compared to the 2030 baseline. Across the three scenarios, the overall trends indicate that aggressive shifts in Vietnam's energy mix have significant impacts on its export performance. This finding aligns with Antimiani et al. (2016), who also observed substantial effects of energy policy changes on the trade patterns of many countries. Scenario 1 showed considerable declines in total exports to major trading partners, with exports to China dropping by $9,669 million (–28.56%). In addition, the electronics and electrical equipment sectors experienced substantial declines in absolute exports across all trading partners. There are two main reasons for this decline. First, the sector suffers from capital diversion, where significant capital was reallocated to promote the production of gas-fired energy, as previously evidenced by a 46% decline in capital use. Second, increased production costs induced Vietnamese exporters to raise prices, making their products less competitive than those from other countries. Closer inspection of model linkages confirms this speculation by revealing the policy-induced impact of 2.4%, 7.5%, and 0.73% increases on prices of skilled labour, capital, and electronics and

Table 4. Impact of changes in energy mix on export of some main commodities of Vietnam relative to the 2030 baseline (US$ million)

	Scenario 1	Scenario 2	Scenario 3
Export to China	–9,238 (–12.07%)	62 (0.06%)	–3,679 (–4.31%)
Textiles & wearing apparel	–31 (–0.68%)	–2 (–0.05%)	63 (1.38%)
Electronics & electrical equipment	–9,669 (–28.56%)	155 (0.46%)	–4,659 (–13.76%)
Machinery & other equipment	–3 (–0.29%)	–12 (–1.32%)	82 (9.17%)
Other manufacturing products	203 (4.74%)	–37 (–0.87%)	301 (7.05%)
Export to Japan	–1,974 (–7.07%)	–78 (–0.28%)	–835 (–3.56%)
Textiles & wearing apparel	–175 (–4.14%)	–2 (–0.04%)	–89 (–2.10%)
Electronics & electrical equipment	–1,291 (–25.19%)	19 (0.37%)	–706 (–13.72%)
Machinery & other equipment	–182 (–20.60%)	–6 (–0.63%)	–113 (–12.83%)
Other manufacturing products	–193 (–5.04%)	–32 (–0.83%)	22 (0.56%)
Export to Korea	–1,411 (–4.81%)	–28 (–0.14%)	–223 (–1.00%)
Textiles & wearing apparel	–75 (–2.13%)	–2 (–0.05%)	–7 (–0.20%)
Electronics & electrical equipment	–1,308 (–16.88%)	25 (0.33%)	–390 (–5.03%)
Processed food products	–3 (–0.28%)	–1 (–0.07%)	13 (1.47%)
Other manufacturing products	–20 (–1.19%)	–32 (–0.80%)	80 (4.83%)
Export to India	3 (2.95%)	–44 (–0.68%)	69 (8.96%)
Metals	–186 (–20.36%)	–49 (–5.32%)	46 (5.01%)
Electronics & electrical equipment	–108 (–5.47%)	6 (0.28%)	180 (9.13%)

table 4 continued

	Scenario 1	**Scenario 2**	**Scenario 3**
Agricultural products	84 (29.93%)	9 (3.17%)	54 (19.15%)
Other services	58 (14.85%)	3 (0.82%)	69 (17.76%)
Export to the US	–3,167 (–5.11%)	–148 (–0.23%)	–625 (–1.16%)
Textiles & wearing apparel	–170 (–1.21%)	–7 (–0.05%)	142 (1.01%)
Electronics & electrical equipment	–2,507 (–23.76%)	37 (0.35%)	–1,263 (–11.98%)
Machinery & other equipment	–151 (–11.19%)	–7 (–0.54%)	–64 (–4.73%)
Other manufacturing products	–418 (–2.98%)	–108 (–0.77%)	388 (2.77%)
Export to Western Europe	–5,203 (–7.56%)	11 (–0.10%)	–152 (–5.03%)
Textiles & wearing apparel	–144 (–3.13%)	–2 (–0.04%)	142 (1.63%)
Electronics & electrical equipment	–4,616 (–26.44%)	61 (0.35%)	–2,634 (–15.09%)
Other services	–270 (–6.47%)	11 (0.34%)	–152 (–4.81%)
Other manufacturing products	–315 (–3.78%)	–58 (–0.69%)	–25 (–0.30%)
Export to rest of the world	–7,191 (–6.84%)	–193 (–0.22%)	–202 (–1.84%)
Electronics & electrical equipment	–6,073 (–21.99%)	105 (0.37%)	–2,587 (–9.37%)
Processed food products	22 (0.42%)	–4 (–0.08%)	120 (2.32%)
Other services	–270 (–4.51%)	24 (0.41%)	–202 (–3.36%)
Other manufacturing products	–200 (–3.23%)	–50 (–0.81%)	175 (2.83%)

Source: calculated from the GTAP-E-Power model result.

electrical equipment, the three most important inputs for the production of electronics and electrical equipment. These findings are consistent with the study by Doan et al. (2019), which highlighted the vulnerability of Vietnam's electronics sector to varying input prices. On the other hand, exports from light manufacturing sectors such as textile and apparel, food processing, other manufacturing, and services were not significantly affected by the policy. This is because these sectors are generally less energy-intensive compared to heavy industries like electronics manufacturing. Consequently, increases in energy costs resulting from the shift towards gas-fired power are not likely to lead to significant cost rises.

Scenario 2 appears to have the least disruptive impact on Vietnam's export economy compared to the other two scenarios, with most changes being within ±1% of the baseline. Notably, exports to China show a slight overall increase of 0.06% ($62 million), primarily driven by growth in the electronics and electrical equipment sector (0.46% or $155 million). Similar modest gains in electronics exports were observed across other major markets, including Japan, Korea, the US, and Western Europe. However, some sectors and destinations do experience minor declines. For instance, machinery and other equipment exports to China decreased by 1.32% ($12 million), and exports of other manufacturing products showed slight decreases across several markets. Interestingly, exports to India are mixed with a slight overall decline of 0.68% ($44 million), despite growth in the electronics and agricultural products sectors. The textiles and wearing apparel sector, crucial to Vietnam's export economy, remains remarkably stable across all destinations, with changes not exceeding –0.05%.

The exports in Scenario 3 remain below baseline levels, and energy-intensive sectors like electronics still face substantial declines. These trends are generally consistent with previous results regarding sectoral outputs. The most notable figure is the stark decline in electronics exports to China of $4,659 million (–13.76%), followed by a decline to Japan by $706 million (–13.72%) and to the USA by $1,263 million (–11.98%). However, electronics exports to India registered a significant increase of 9.13% ($180 million). Analysis of the export decline to China reveals that import demand for electronics increased by 3.92% in China, but the import price to China also decreased by –5.75%. However, this was heavily compensated for by the drop in the price of the imported composite of electronics and electrical equipment in China (–7.28%), suggesting that the policy hampered the international competitiveness of the Vietnamese electronics industry compared to other regions exporting to China. On the other hand, the textiles and wearing apparel sector registered export growth to some destinations, with increases of $63 million (1.38%) to China, $142 million (1.01%) to the USA, and $142 million (1.63%) to Western Europe. This can be explained by increased coal usage leading to lower energy costs and production expenses, which in turn improves the competitiveness

of Vietnamese light manufacturing commodities in these markets. Exports of machinery and other equipment show mixed results, with an increase in China (9.17%) but a decrease in Japan (–12.83%) and the US (–4.73%). This is due to China's demand for machinery related to the industrial and energy sectors. Processed food products register increases across several markets, particularly in the rest of the world (2.32%).

Table 5 presents the macroeconomic and environmental impacts on Vietnam's economy of three different energy mix scenarios relative to the 2030 baseline. The most severe impacts can be observed in Scenario 1, where GDP decreased by 8.02%, and welfare by $14,254 million, which is primarily due to a significant negative technical change effect of $20,925 million. The trade balance worsens by $7,001.81 million, indicating increased imports or decreased exports, possibly due to higher energy costs and reduced competitiveness in key sectors like electronics. CO_2 emissions rose by 18.04%, primarily driven by a 39.46% increase in coal emissions, despite the reduction in coal-fired power, suggesting inefficiencies or increased coal use in other sectors.

Table 5. Impact of changes in energy mix on GDP, trade balance, emissions and welfare of Vietnam relative to the 2030 baseline

	Scenario 1	Scenario 2	Scenario 3
GDP (%)	–8.02	–1.02	–3.31
Trade balance (US$ million)	–7,001.81	151.34	–1,493.26
Welfare (US$ million)	–14,254.00	–1,888.68	–8,600.05
Welfare—Allocative efficiency (US$ million)	–1,151.96	–461.56	–813.55
Welfare—Endowment effect (US$ million)	4,467.02	–132.82	3,853.50
Welfare—Technical change effect (US$ million)	–20,925.00	–1,313.11	–12,601.20
Welfare—Terms of trade effect (US$ million)	3,930.47	83.69	1,454.91
CO_2 emission (%)	18.04	0.78	28.89
CO_2 emission—coal (%)	39.46	0.82	51.50
CO_2 emission—oil (%)	–6.69	0.36	0.57
CO_2 emission—gas (%)	–18.24	–1.27	15.96
CO_2 emission—oil products (%)	–6.94	1.43	–8.95

Source: calculated from the GTAP-E-Power model result.

In contrast, Scenario 2, featuring a reduction in coal-fired power and a slight increase in renewables, demonstrated the least disruptive impact on the economy and environment. GDP declined marginally by 1.02%, and welfare by $1,888.68 million, with minimal negative effects on allocative efficiency and endowments. The trade balance slightly improved by $151.34 million, reflecting stable export performance and reduced import dependency. CO_2 emissions increased negligibly by 0.78%, highlighting the environmental benefits of reducing coal reliance and promoting renewables. While this result may be at odds with prior expectations regarding the energy shift, it can be attributed to industries' ability to substitute electricity input with coal and other fuels in response to lower electricity input so that the equilibrium production quantity can be achieved. This is consistent with a previous meta-analysis by Stern (2012), which suggested that there is generally some degree of substitutability between energy inputs of manufacturing industries and is further evidenced by a rise in emissions resulting from the consumption of crude oil and oil products, even though Vietnam's generation sectors consumed very little of this commodity in Scenario 2. Scenario 3, which significantly increases coal-fired power and decreases renewables, resulted in a moderate GDP decline of 3.31% and a welfare loss of $8,600.05 million. However, it led to the highest rise in CO_2 emissions at 28.89%, primarily due to a 51.5% spike in coal emissions. These results suggest that Scenario 2 offers a balanced approach, minimising economic disruptions while achieving environmental benefits, whereas Scenarios 1 and 3 pose significant economic and environmental challenges for Vietnam.

Conclusions and policy implications

We examined the economic and environmental implications of transitioning to different energy generation mixes through three scenarios: a gas-heavy mix, a renewable-focused mix, and a coal-dominant mix. Notably, the renewables-focused scenario (Scenario 2) emerged as the most balanced approach, minimising economic disruptions while achieving environmental benefits. This led to a marginal GDP decline of 1.02% and a slight increase in CO_2 emissions of 0.78%. In contrast, the gas-heavy (Scenario 1) and coal-dominant (Scenario 3) scenarios resulted in more substantial economic costs and environmental impacts. In the gas-heavy scenario, this sector experienced a significant decline in output and exports, suggesting the possibility of capital diversion to power generation sectors. Conversely, the coal-heavy scenario showed adverse impacts on output, export and welfare.

It is worth reiterating that the shift toward renewable energy is indisputably important for achieving better environmental outcomes for Vietnam. However,

our findings suggest that imposing a strict limit on the output of gas, coal and renewable power, as in Scenario 1, necessitates reallocating capital from important industries such as electronics and textiles to the gas and renewable energy sectors, which in turn impacts the export of these sectors. Therefore, we recommend setting gradual targets for renewable energy adoption, while providing incentives and support for affected industries to improve their energy efficiency and transition to cleaner technologies. In addition, special treatment for the electronics sector—one of Vietnam's key industries—is needed to mitigate its heavy output decline resulting from the implementation of Scenario 1. First, it is important to ensure that the electronics sector enjoys sufficient access to financing when the capital shift takes place. This could involve providing tax incentives and compensation for the electronics firms affected by capital shortages to upgrade production facilities, and to sustain production and maintain the workforce. Second, maintaining an affordable supply of intermediates and energy for electronics firms can mitigate the adverse impact of capital shift, since the result shows some flexibility in input substitution of the electronics industry. Relevant strategies might involve imposing industrial energy pricing policies that protect electronics firms from excessive volatility in energy price and reduce the import tax of key materials such as semiconductors, precision metals, and specialised components.

Our model also points out that production in the coal power sector will become inefficient if its output is fixed. This is largely due to the inability of this sector to substitute coal input with other fuels. Despite the model's assumption of endogenous productivity, which may not reflect real-world responses to fixed generation output, this phenomenon still highlights a key bottleneck of the coal power sector, namely, its reliance on coal inputs. Therefore, we recommend expediting the adoption of co-fired coal technology to enhance the efficiency and sustainability of coal power generation in Vietnam. Co-firing involves blending coal with alternative fuels such as biomass, natural gas, crude oil or refined oil products in the combustion process. This approach is less capital-intensive than a complete transition to other energy sources and can decrease carbon emissions, improve output productivity, and, most importantly, allow existing coal power plants to substitute coal with other inputs, in order that the industry can reduce its reliance on pure coal inputs. To support the adoption of co-fired coal technology, policymakers should consider providing financial incentives such as subsidies or tax breaks for initial investments in co-firing infrastructure and even for a certain period after the plant has come into full operation.

Given the prediction that substantial capital investment is required to support renewable energy expansion while minimising economic consequences, we recommend employing a combination of different financing instruments, including participation in international climate initiatives and improving domestic investment. First, international funding sources such as the Green

Climate Fund (GCF) and Just Energy Transition Partnerships (JETP) can provide concessional financing to facilitate large-scale renewable energy projects, thus reducing the financial burden on domestic resources. Another approach to secure foreign funding involves selling carbon credits obtained through renewable investments in international markets and reinvesting these funds in green energy infrastructure. Second, domestic investment should be improved through supporting private green investment and relevant industries, including the manufacture of power generation equipment, solar panels, and gas turbines. Specifically, domestic renewable energy manufacturers should be supported by tax credits, low-interest loans, and preferential financing so that their output can be improved, which in turn raises domestic capital accumulation for energy sectors. Support for private investments in green energy projects should also be considered, preferably through streamlined administration, loan guarantees, high feed-in tariffs (FITs), and investment tax credits.

Although Scenario 2 yielded the most optimistic outcomes, our model also predicted that domestic demand for machinery, other equipment, vehicles, parts & other transport equipment will experience a decline as a result of this transition. Therefore, we recommend supplementing the energy transition strategy with plans to improve the quality of labour force in affected sectors, enabling them to substitute the decline in important inputs with more skilled labour. Specific measures might include increasing the admissions quota for vocational schools and providing financial support for workforce retraining to facilitate the transition of workers into affected manufacturing sectors such as vehicles, renewable energy technology, and machinery. Furthermore, we recommend implementing policies for the energy-intensive sectors that cater to the growing renewable energy market. Specific measures might include targeted tax reductions and low-interest loans for domestic manufacturers of important renewable energy components such as turbines, solar panels, and batteries. Similar policies aiming to attract international manufacturers in green technology and sustainable manufacturing could also be considered. By employing these measures, Vietnam can effectively mitigate the negative impacts of the energy transition on key industries, while simultaneously creating export opportunities and attracting investments.

Some limitations need to be acknowledged in this study. First, GTAP-E--Power has limitations that are inherent to other CGE models, particularly regarding the assumed form of the production function. To be specific, the nested CES production function implies that inputs situated at the same level (nest) share the same elasticity of substitution. This assumption may not hold in certain contexts, for instance, in heavy manufacturing and fossil fuel-based power generation industries, where powered machinery (i.e. capital-energy composite) can be easily adjusted for higher working capacity if operators become scarce, but these trained operators cannot be easily replaced with unskilled manpower. This assumption may lead to transition costs

being underestimated in industries where specialised labour and capital-intensive technologies are crucial in production processes, because switching from skilled to unskilled labour can be more costly than from skilled labour to powered machinery. This shortcoming can be addressed by adopting firm heterogeneity in model design, where some industries can take a different production structure to reflect these complexities. Second, the current GTAP-E-Power model lacks empirically estimated elasticities in production nests deep down the production structure, e.g., between electricity and non-electricity goods or between coal and non-coal goods. This issue can be remedied by better data availability and more sophisticated approaches in estimation strategies, which should be tackled by future econometric studies. Third, the current CGE results only represent a snapshot of the economy at one point at which all policy shocks take place, rather than the trends of policy impacts over time. This shortcoming stems from the static nature of the GTAP-E-Power model but can be addressed by adopting a dynamic CGE model. In the context of energy transition policies, an examination of whether the capital requirements can be offset by capital accumulation-phased implementation of power output change in a dynamic CGE framework would allow a better understanding of the outcomes of industries in response to capital shifts over time. Another benefit of a dynamic framework is that it could better quantify effects that cannot exist instantaneously, such as reduced energy costs and fossil imports, all of which contribute to improved growth. This could provide a better assessment of the cumulative benefits of each scenario over time.

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The impact of women's economic empowerment on human development in sub-Saharan Africa: A panel quantile regression approach

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Abstract

This paper uses a panel quantile regression approach to study the economic empowerment of women in sub-Saharan Africa and how it impacts human development. Analysing data collected from 42 countries covering the period 2000–2023, the study looks at various indicators of women's economic empowerment. The impacts of women's economic empowerment are found to differ depending on quantile levels; female entrepreneurship shows a significant impact only at higher levels. Across all levels, marriage rights and workplace participation repeatedly show positive impacts. The Gender Development Index's significant positive impact underscores the importance of gender equality for overall human development. Parenting rights

Keywords

- women's economic empowerment
- human development
- sub-Saharan Africa
- panel quantile regression
- gender equality

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and mobility show positive results at most levels, though there are some variations.

JEL codes: C23, J16, O15, O55

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Introduction

Women's empowerment (WE) is becoming ever more important as a main driver of general human progress, particularly in the economic sphere. This link is particularly relevant in sub-Saharan Africa (SSA), a continent with enormous potential for development, yet also with major obstacles. Understanding the dynamics between women's economic empowerment (WEE) and human development in this area is increasingly important as the world works towards the Sustainable Development Goals by 2030.

Women in the SSA are crucial for their economies; they help greatly with agricultural output, entrepreneurship, and the unofficial sector (Palacios-Lopez et al., 2017). However, they still face numerous challenges to participate fully in the economy, such as limited access to formal employment, financial services and education (Hallward-Driemeier & Hasan, 2013). These limitations not only impede women's own development, but they may also impede the advancement of society as a whole.

WEE has several meanings: labour force participation, access to and control over financial resources, and the capacity to make strategic life decisions (Kabeer, 1999). Human development, as conceptualised by Sen (1999) and operationalised via the Human Development Index (HDI), emphasises extending people's freedoms and capabilities outside of simple economic development. Although an increasing amount of research points to a favourable relationship between women empowerment and different development outcomes worldwide (Duflo, 2012), the particular dynamics of this link in the SSA remain under-researched. Furthermore, most of the current studies rely on cross-sectional data or country-specific case studies, which limits our understanding of how this relationship changes over time and across various national settings within the region.

This paper aims to close these gaps by analysing the impact of WEE on human development across the SSA[4] over the period 2000–2023. We use

[4] List of countries included in the study: Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Democratic Republic of the

a Method of Moments Quantile Regression (MM-QR) panel approach to look at data from 42 countries and provide an in-depth study of this important link. Our study adds to the body of knowledge in a number of respects. Firstly, it thoroughly analyses WWE in the SSA using a variety of indicators. Secondly, the MM-QR approach enables one to gain an understanding of the heterogeneous effects of WWE. Finally, this study helps to broaden knowledge in development studies by including African feminist points of view and context-specific issues.

The basic structure of this article is as follows: Section 1 offers a summary of literature. Section 2 describes our hypotheses, econometric technique and data sources, while Section 3 addresses the empirical results within the context of current research. Section 4 presents the discussions about our results. The final section concludes with important observations and recommendations for the future directions of inquiry.

1. Literature review

In particular with regard to the SSA, WEE and human development have attracted a lot of interest recently. This review of the literature investigates theoretical frameworks, empirical studies, and contextual elements that highlight the impact of WEE on human development in the region. By aggregating already published studies, this review attempts to give a picture of the present level of knowledge and point out areas for future research.

According to Kabeer (1999), empowerment is the enhancement of individuals' capacity to make strategic life decisions in a context that had previously been denied to them. Golla et al. (2011) offer a more precise definition of WEE, asserting that a woman attains economic empowerment when she has the capacity to thrive and grow economically, as well as the authority to make and implement economic decisions that may impact development outcomes. Sen's capability approach primarily informs the concept of human development, which closely links to WEE. Sen (1999) argues that development should expand people's actual freedoms, not just increase national incomes. The UNDP Human Development Index operationalised this approach in 1990, measuring development through three dimensions: a long and healthy life, access to knowledge, and a decent standard of living. Building on Sen's work,

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Congo, Djibouti, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Ivory Coast, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Republic of the Congo, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe.

Nussbaum (2011) offers a list of fundamental skills that every democracy should foster, thus augmenting our knowledge of human progress.

Many theoretical models connect WEE to more general results in human development. Duflo (2012) suggests a bi-directional link between women empowerment and economic development, contending that while development itself can significantly help to reduce inequality between men and women, empowering women may help development. While Klasen and Lamanna (2009) offer a theoretical framework for how gender discrepancies in education and employment might affect economic growth, which in turn influences human development, Kabeer (2005) investigates how gender equality in these spheres might lead to other development outcomes.

When examining WEE in the SSA, it is crucial to consider the perspectives of African feminists. Arguing for the need-to-know local social structures and practices, Oyěwùmí (1997) questions the application of Western gender concepts to African societies. Tamale (2020) also stresses the need for decolonial approaches to grasp African women's experiences and empowerment, underscoring the need for context-specific research and treatments. These points of view emphasise the need to base research and policy on local reality and avoid the unquestioning acceptance of Western ideas in African settings.

Empirical studies across the globe support the need for WEE to achieve results in development. Using panel data from 1960–2000, Klasen and Lamanna (2009) examined a wide range of nations and found that gender disparities in employment and education greatly reduce economic growth. Verick (2014) offers a thorough analysis of the U-shaped link between female labour force participation and economic growth. Using Global Entrepreneurship Monitor statistics, Kelley et al. (2017) demonstrated that women's rates of entrepreneurship have been rising worldwide, benefiting employment creation and economic growth.

Financial inclusion also significantly influences WEE. Using Global Findex data, Demirgüç-Kunt et al. (2020) demonstrate that even if financial inclusion is generally rising, notable gender discrepancies still exist, especially in developing nations. Psacharopoulos and Patrinos (2018) present an updated worldwide picture of returns to education, demonstrating that women often have greater returns than men. These studies provide a broad framework for evaluating the possible effects of WEE on development outcomes.

With an eye especially towards the SSA, a number of studies have looked at several facets of women's financial empowerment. Examining data from 1991–2013 for 30 sub-Saharan African nations, Bandara (2015) found a positive correlation between women's labour force participation and economic growth. Examining trends in female labour force participation over 24 sub-Saharan African nations, Comblon et al. (2017) found notable variation in both patterns and drivers.

Regarding entrepreneurship, Campos and Gassier (2017) examined data from the SSA and concluded that women entrepreneurs have enormous un-

realised potential but also suffer from particular limitations. Training programmes have a greater impact on women entrepreneurs, according to a meta-analysis of African entrepreneurship initiatives by Campos et al. (2018). Aterido et al. (2013) found that women-owned firms across 37 African countries are less likely to receive loans.

Agriculture is still a vital industry for women's economic involvement in SSA. Challenging conventional wisdom, Palacios-Lopez et al. (2017) estimated women's contribution to agricultural labour using nationally representative data from 6 African countries. Reviewing data on WE in agriculture, Meinzen-Dick et al. (2019) underline the need for context-specific policies and interventions.

An area of growing interest is how technology might empower women economically. Asongu and Odhiambo (2018) found positive results when they examined the link between female economic participation in the SSA and mobile phone penetration. In 11 African nations, Mothobi and Grzybowski (2017) examined the gender disparity in mobile phone ownership and use, indicated important obstacles for women. These studies demonstrate the potential for technology to accelerate WEE in the region.

Ultimately, WEE depends much on the legal and policy environment. Emphasising recent changes and ongoing challenges, Hallward-Driemeier and Hasan (2013) offer a thorough investigation of legal and regulatory hurdles to WEE in Africa. Under the framework of the Sustainable Development Goals, UN Women (2019) examines advancements in WEE in Africa, highlighting important policy priorities. These studies underline the need to encourage WEE and human development through favourable legal and policy environments.

2. Hypotheses, data and methods

This study investigates the intricate impacts of WEE indicators on human development within sub-Saharan Africa. Considering the region's distinct socio-economic context, we propose multiple hypotheses regarding WEE's potential contributions to human development:

H1: Increased women's entrepreneurship enhances human development in SSA.
H2: Improved women's assets positively impact human development in SSA.
H3: Increased female labour force participation enhances human development in SSA.
H4: Enhanced workplace conditions for women influence human development in SSA.
H5: Enhancing gender development contributes to improved human development in SSA.

H6: Marriage rights and supportive parenthood policies enhance women's social conditions and contribute to human development in SSA.

H7: Enhanced women's mobility positively influences human development in SSA.

H8: Reducing occupational segregation and closing the gender pay gap positively contribute to human development in SSA.

Women's entrepreneurship generates employment, increases household incomes, and enhances community welfare, thereby fostering human development (H1). Reducing gender inequalities in inheritance and property law, supported by customary law and judicial precedent, empowers women to secure economic resources. This empowerment enables women to make strategic investments in health, education, and family well-being, thereby enhancing key human development indicators across the region (H2). Increased women's participation in the labour force enhances economic productivity and household incomes, thereby elevating living standards (H3). Guaranteeing women's legal abilities, safeguarding them from sexual harassment and discrimination, and fostering equitable career prospects together enable women to enhance economic growth and social advancement, thereby increasing human development (H4). Reducing gender disparities facilitates holistic human development through a more equitable distribution of resources and opportunities (H5). Secure marriage rights and supportive parenthood policies enable women to make decisions that positively impact their families and communities, thereby promoting human development (H6). Reducing constraints on women's agency and freedom of movement enables them to access better employment opportunities, engage in entrepreneurship, and participate more actively in economic and social activities. These improvements empower women to contribute to family welfare and societal progress, thereby promoting overall human development across the region (H7). Ensuring equitable access to diverse occupations and addressing wage disparities empowers women economically, enabling them to make greater contributions to household welfare, societal progress, and overall human development across the region (H8).

This study looks at data from 42 SAA countries from 2000 to 2023. Table 1 shows the dependent and independent variables, along with their sources. Socioeconomic considerations indeed make modelling the impact of WEE on human development complex, particularly in the context of sub-Saharan Africa. To address this complexity and eliminate bias, it is crucial to include all important factors in the analytical framework.

Several recent studies have attempted to tackle this challenge, providing more comprehensive and nuanced approaches. In line with the findings from these studies, including (Chikh-Amnache et al., 2023) and (Chikh-Amnache & Mekhzoumi, 2024), we apply the following model to our empirical investigation:

Table 1. Description of variables

Abbreviation	Variable name	Description	Source
Dependent variable			
HDI	Human Development Index	a composite indicator reflects average performance across essential dimensions of human development: health and longevity, knowledge, and standard of living	UN Development Programme
Independent variables			
FEPI	Female Entrepreneurship Indicator Score	evaluates the challenges that women encounter when starting and running businesses	Gender Data Portal
FPYI	Female Pay Indicator	laws that regulate occupational segregation and the gender pay gap	
FWPI	Female Workplace Indicator	women's legal rights, abilities, and workplace safeguards against sexual harassment and discrimination impact their career choices	
FPHI	Female Parenthood Indicator	examines the regulations that impact women's employment prior to, during, and following childbirth	
FMRI	Female Marriage Indicator	evaluates the legal limitations associated with divorce and marriage	
FMBI	Female Mobility Indicator	mobility assesses limits on a woman's agency and freedom of mobility	
FASI	Female Assets Indicator	examines gender inequality in inheritance and property law and instances where customary law and judicial precedent support legal systems	
FMLF	Female to male labour force participation	the ratio of the female labour force participation to the male labour force participation	
GDI	Gender Development Index	assesses disparities between genders in health, education, and economic resource control	UN Development Programme
Control variables			
GDPpc	GDP per capita	in (constant 2015 US$) prices	World Bank Group
HE	Current health expenditure	covers healthcare items and services used throughout the year (% of GDP)	
GEE	Government expenditure on education	general government expenditure on education (current, capital, and transfers), expressed as a percentage of GDP	
PVE	Political stability and absence of violence/terrorism	gauges the probability of political instability and/or politically driven violence, such as terrorism	

Source: own compilation.

$$HDI_{it} = \beta_0 + \beta_1 FEPI_{it} + \beta_2 FPYI_{it} + \beta_3 FWPI_{it} + \beta_4 FPHI_{it} + \beta_5 FMRI_{it} + \\ + \beta_6 FMBI_{it} + \beta_7 FASI_{it} + \beta_8 FMLF_{it} + \beta_9 GDPpc_{it} + \beta_{10} HE_{it} + \\ + \beta_{11} GEE_{it} + \beta_{12} PVE_{it} + \varepsilon_{it} \quad (1)$$

The traditional approach to panel data analysis, Ordinary Least Squares (OLS) with fixed effects, has been widely used due to its simplicity and computational efficiency. This method effectively controls for time-invariant unobserved heterogeneity but is limited to estimating effects on the conditional mean. In contrast, quantile regression methods for panel data aim to provide a more comprehensive view of the relationship between variables across different quantiles of the conditional distribution. Quantile regression has become an essential tool in econometrics, allowing researchers to examine how covariates affect the entire distribution of the dependent variable, not just its mean. However, applying quantile regression to panel data, particularly in the presence of fixed effects, has posed significant challenges. A generalisation of a quantile regression data generating function can be written as follows:

$$y_i = \beta_0(\tau) + \beta_1(\tau) X_{i1} + \beta_2(\tau) X_{i2} + \ldots + \beta_k(\tau) X_{ik} \quad (2)$$

Based on this specification, several characteristics should be considered:

- slopes $\beta_k(\tau)$ vary across quantiles only if the model is heteroskedastic;
- quantile regression can be considered as a semi-parametric-varying coefficient model, with unobserved running variable (τ);
- coefficients are percentile specific;
- it is possible to separate location effects (mean) from scale effect (deviation from the mean).

Quantile regressions are nonlinear models. Thus, one cannot just add dummies to address group fixed effects:

$$Q_\tau(y|x) = \beta_0(\tau) + \beta_1 X(\tau) + \sum \delta(\tau)_g \quad (3)$$

This creates an incidental parameter problem. Neither $\delta(\tau)s$ nor βs would be estimated consistently. Koenker (2004) proposed the penalised quantile regression method as one of the first attempts to handle quantile regression in panel data. This method incorporates fixed effects via a penalty term, allowing for quantile effects estimation while controlling for unobserved heterogeneity. However, it can suffer from the incidental parameter problem when the number of fixed effects is large relative to the sample size. Koenker (2004) assumes fixed effects only have an impact on location and shrink individual effects:

$$y_i = \beta(\tau) X + \delta_g \quad (4)$$

Canay (2011) proposed a two-step approach that first estimates fixed effects using a conditional mean model and then performs quantile regression on the demeaned data. This method is intuitive and relatively simple to implement but may introduce bias, particularly when the effects of covariates vary substantially across quantiles:

$$y = \beta X + \delta_g \tag{5}$$

$$Q_\tau(y - \delta_g | X) = \beta(\tau)\, X \tag{6}$$

The MM-QR approach, introduced by Machado and Silva (2019), represents a significant advancement in this field. MM-QR transforms the quantile regression problem into a set of moment conditions, allowing for efficient estimation even with high-dimensional fixed effects. This method avoids the incidental parameters problem and is computationally efficient for large datasets, addressing the key limitations of previous approaches. This method was developed to incorporate individual fixed effects. In principle, it is an extension of a strategy to estimate quantile regression coefficients using a restricted location-scale model, assuming the following structure:

$$y_i = X_i \beta + \varepsilon X_i \gamma \tag{7}$$

Thus, the quantile regression model is given by:

$$Q_\tau(y | X) = X(\beta + F_\varepsilon^{-1}(\tau)\gamma) = X\beta(\tau)\, X \tag{8}$$

OLS with fixed effects remains valuable for its simplicity and when the focus is on average effects. Traditional quantile regression or Koenker's penalized approach may be preferred when the number of fixed effects is moderate. Canay's two-step method offers a straightforward alternative when the assumption of location shift (i.e. fixed effects affect all quantiles equally) is plausible. However, for researchers dealing with large panel datasets and interested in distributional effects, MM-QR offers significant advantages. Its ability to handle high-dimensional fixed effects efficiently, coupled with its robustness to outliers and non-normal errors, makes it a powerful tool in modern econometric analysis (Machado & Silva, 2019).

We investigate the impact of WEE on human development in a panel of 42 sub-Saharan African countries, utilising the MM-QR approach for panel fixed effects. We use the MM-QR approach to project the distribution of conditional economic growth, which allows us to consider the possibility of heterogeneity. The model is as follows:

$$HDI_{it} = \alpha_i + X'_{it}\beta + (\delta_i + Z'_{it}\gamma)\, U_{it} \tag{9}$$

where $P\{\delta_i + Z_{it}' \gamma > 0\} = 1$. Individual *i* fixed effects are denoted by (α_i, δ_i), $i = 1, 2, \ldots, n$, and Z is a k-vector of transformations of the elements of X with probability 1 that are known to be differentiable. Model (9) could have the following expansions:

$$Q_{HDI}(\tau | X_{it}) = (\alpha_i + \delta_i q(\tau)) + Z_{it}' \gamma q(\tau) \quad (10)$$

X_{it} denotes the independent variables. Conditional on the location of explanatory variables, the response variable HDI has a quantile distribution denoted by $Q_{HDI}(\tau | X_{it})$. We define the τth quantile $(0 < \tau < 1)$ of the conditional distribution of the dependent variable, considering a set of independent variables X_{it}. The scalar coefficient *i* denotes the quantile-τ fixed effect, either for individual *i* or the distributional effect at τ. The distributional influence, unlike the habitual fixed effect, does not entail a change in location. As a result, the distributional effect replaces the influence of time-invariant individual traits, which, like other variables, could have different effects on different areas of HDI's conditional distribution. Minimising the following optimisation yields the τ-th sample quantile estimate shown by $q(\tau)$:

$$\min_q \sum_i \sum_t \rho_\tau \left(\hat{R}_{it} - (\hat{\delta}_i + Z_{it}' \hat{\gamma}) q \right) \quad (11)$$

The check-function is indicated by $\rho_\tau(A) = (\tau - 1) AI\{A \leq 0\} + \tau AI\{A > 0\}$.

3. Results

Before commencing the analytical approach, econometric estimates must address multi-collinearity doubts through correlation analysis and the variance inflation factor (VIF). Tables A2 and A3 in the Appendix show that multicollinearity does not pose a problem for our empirical analysis. The correlation between FWPI and FMRI is the strongest at 0.578. The VIF values for all variables are below 5. Five quantiles of 0.10, 0.30, 0.50, 0.70, and 0.9 were selected in the quantile regression based on Formula (10) for estimating the coefficients of the dependent variables.

The result that women's entrepreneurship (FEPI) has a statistically positive and significant effect on the dependent variable at the two highest quantiles supports Hypothesis 1. This implies that an increase in the number of women starting their own businesses is advantageous for the advancement of human development in SSA. Women entrepreneurs in SSA play a crucial role in generating employment opportunities, reducing unemployment rates, and fostering economic growth. They significantly increase household incomes,

reinvesting a higher proportion of earnings into their families, which translates into improved access to education, healthcare, and nutrition—key components of human development. Moreover, women entrepreneurs often address community needs, enhancing overall welfare. The concentration of impact at higher quantiles suggests a more pronounced effect in regions with stronger institutional frameworks and financial systems. The fact that there was no significant effect at lower quantiles suggests that women's entrepreneurship may need more help, like micro-finance services, targeted training programmes, and policies that remove gender-based barriers, in order to reach its full potential at all levels of development in SSA. Creating an enabling environment that fosters women's economic empowerment, including improved access to education, financial services, and supportive networks, is crucial to amplifying the positive effects of female entrepreneurship on human development throughout the region.

The result that women's assets (FASI) have positive and statistically significant coefficients across most quantiles shows how important fair property rights and inheritance laws are for human development in SSA. This finding strongly supports Hypothesis 2, namely that enhancing women's economic empowerment through improved asset ownership positively impacts overall human development. By reducing gender disparities in inheritance and property ownership, women gain access to secure economic resources, enabling them to make strategic investments in health, education, and family well-being. The ripple effects of women's economic empowerment extend beyond individual households, fostering broader economic growth and social development across the region.

The negative coefficients for female labour force participation (FMLF) at most quantiles show that the relationship between FMLF and human development is complex. This is contrary to Hypothesis 3, which states that having more women working has a positive effect on human development in SSA. While increased female labour force participation is often associated with economic growth and societal progress, the negative coefficients suggest that the quality and nature of employment play a critical role. Many women in SSA work in low-paying, informal or precarious jobs that may not significantly improve household welfare or meaningfully contribute to broader human development outcomes. Moreover, women may enter the labour force out of economic necessity rather than empowerment, which could limit their capacity to invest in health, education, and family well-being. Additionally, the lack of supportive policies such as childcare services, maternity leave and workplace protections may exacerbate the challenges women face, leading to trade-offs between work and caregiving responsibilities. These findings emphasise the need for policies that not only promote women's participation in the labour force but also ensure access to quality jobs and supportive infrastructure to maximise the positive impact on human development.

The findings indicate that women's workplace (FWPI) has a significant positive influence across all quantiles, corroborating Hypothesis 4 that improved working circumstances for women positively affect human development in SSA. This conclusion underscores the essential importance of women's legal rights, competencies, and workplace protections—such as measures against sexual harassment and discrimination—in empowering women to make significant career decisions and contribute successfully to economic and social advancement. Ensuring equal remuneration, secure working conditions and fair chances enables women to attain financial autonomy and career advancement. This empowerment enhances individual well-being and has a multiplier impact on societal development by augmenting family earnings, facilitating improved education and health results, and advancing gender equality. The uniform beneficial effect across all quantiles indicates that these workplace enhancements are advantageous for nations at different stages of human development, making them a vital policy priority for promoting sustainable development in SSA.

The GDI's consistently strong positive impact across all quantiles in the study underscores its essential role in promoting human development in SSA. This finding supports the Hypothesis 5, which asserts that enhanced gender development, indicative of diminished inequalities in health, education, and economic resources, positively influences human development. Addressing gender disparities in access to healthcare, education and economic opportunities can result in significant improvements in human development outcomes. These findings highlight the significance of targeted policies designed to mitigate gender inequality, as such initiatives promote the establishment of more equitable societies and support sustainable development throughout sub-Saharan Africa.

The variables that measure women's marriage (FMRI) and parenthood (FPHI) have positive effects that are significant across most quantiles. This supports Hypothesis 6 that marriage rights and policies that support parenthood improve women's social conditions and contribute to human development in SSA. Enhanced marriage rights, including secure property ownership, empower women by increasing their bargaining power and decision-making capabilities within households, leading to improved family welfare. Policies that support parenthood, such as maternity protections and childcare provisions, boost the ability of women to reconcile family responsibilities with economic participation. This dual empowerment enhances health outcomes for mothers and children, promotes educational investments, and contributes to overall economic stability. The findings indicate that addressing these social conditions enhances the well-being of individual women and produces a multiplier effect on societal advancement, thereby rendering these policies essential elements of sustainable human development strategies in SSA.

The finding that women's mobility (FMBI) has significant positive coefficients for the three highest quantiles in SSA supports Hypothesis 7 that better

women's mobility has a positive effect on human development. This finding suggests that women's ability to move freely and independently is particularly impactful in higher quantiles of human development, where structural barriers are less pronounced and opportunities for economic participation and entrepreneurship are more accessible. By reducing constraints on mobility—such as restrictive social norms, lack of infrastructure, or safety concerns—women can access better employment opportunities, engage in entrepreneurial activities, and participate more actively in public life. These factors contribute to enhanced household incomes, improved access to education and healthcare, and overall societal progress. The fact that most of the significant effects are in the highest quantiles suggests that mobility has a greater impact in areas where other factors that facilitate it, such as education or access to money, are already present. This highlights the importance of addressing mobility-related barriers as part of broader strategies to empower women and drive sustainable human development across SSA.

The result that women's pay (FPYI) is statistically insignificant across all quantiles in SSA is against Hypothesis 8, which states that closing the gender pay gap and reducing occupational segregation is beneficial for human development in the region. The hypothesis says that giving women equal access to different jobs and reducing wage gaps will help them financially, allowing them to make bigger contributions to household well-being and societal progress. This coefficient is not statistically significant, suggesting data accuracy or validity issues. Other socio-economic barriers may overshadow the impact of legal frameworks addressing occupational segregation and pay disparities, or they may not enforce them adequately. This result highlights the need for further investigation into the implementation and effectiveness of such laws, as well as a deeper exploration of structural factors that may limit their influence on human development in SSA.

The result that political stability and absence of violence / terrorism (PVE) had no statistically significant effect across all quantiles suggests that while stability and positive governance are important for economic growth, they may not have such an effect on human development. This could indicate that other factors, such as institutional effectiveness or social investments, play a more immediate role in shaping human development indicators. Conversely, the significant and positive impact of GDP per capita (GDPpc) across all quantiles reinforces the strong link between economic growth and improvements in living standards, health, and education. The negative coefficients for current health expenditure (HE) in the two highest quantiles highlight potential inefficiencies or inequities in health spending at advanced levels of development. This suggests that increased health expenditure alone may not translate into better health outcomes without addressing systemic issues such as resource allocation, accessibility, and quality of care. Lastly, the positive and statistically significant coefficient for government expenditure on education (GEE) in

Table 2. The MMQR regression on HDI

Variable	OLS		Quantile of HDI				
	location	scale	0.10	0.30	0.50	0.70	0.90
FEPI	–6.37e–06 (0.000111)	0.0001739* (0.0000963)	–0.0002867 (0.0002498)	–0.0001337 (0.0001709)	0.0000126 (0.000103)	0.000135* (0.0000694)	0.0002377*** (0.0000838)
FPYI	0.000096 (0.0001168)	–0.0000241 (0.0001013)	0.0001351 (0.0002651)	0.0001138 (0.000181)	0.0000935 (0.0001083)	0.0000765 (0.000073)	0.0000622 (0.0000883)
FWPI	0.0004566*** (0.0001044)	–0.0000249 (0.0000905)	0.0004967** (0.0002368)	0.0004748*** (0.0001617)	0.0004539*** (0.0000968)	0.0004364*** (0.0000652)	0.0004217*** (0.0000789)
FPHI	0.0003364*** (0.000124)	–0.0000393 (.0001075)	0.0003998 (0.0002814)	0.0003652* (0.0001921)	0.0003321*** (0.000115)	0.0003045*** (0.0000775)	0.0002812*** (0.0000937)
FMRI	0.0006211*** (0.0001953)	–0.0000868 (0.0001693)	0.000761* (0.0004428)	0.0006846** (0.0003024)	0.0006116*** (0.0001811)	0.0005505*** (0.000122)	0.0004992*** (0.0001476)
FMBI	0.0003312** (0.0001594)	–0.0000385 (0.0001382)	0.0003933 (0.0003616)	0.0003594 (0.0002469)	0.000327** (0.0001478)	0.0002999*** (0.0000996)	0.0002771** (0.0001205)
FASI	0.0003156** (0.0001254)	–0.000127 (0.0001088)	0.0005205* (0.0002837)	0.0004087** (0.0001938)	0.0003017** (0.0001163)	0.0002123*** (0.0000784)	0.0001373 (0.0000947)
FMLF	–0.0009692** (0.0004275)	0.0005637 (0.0003708)	–0.0018783* (0.0009626)	–0.0013821** (0.0006583)	–0.0009076** (0.0003963)	–0.0005108* (0.0002672)	–0.0001778 (0.0003224)
GDI	0.4732029*** (0.0619143)	–0.0177801 (0.0536958)	0.5018745*** (0.1405348)	0.4862251*** (0.0959374)	0.4712587*** (0.0574322)	0.4587441*** (0.0386922)	0.4482406*** (0.046812)
GDPpc	0.0000116*** (3.62e–06)	–2.86e–06 (3.14e–06)	0.0000162** (8.19e–06)	0.0000137** (5.59e–06)	0.0000113*** (3.36e–06)	9.30e–06*** (2.26e–06)	7.61e–06*** (2.73e–06)
HE	–.0010341 (0.0007188)	–0.0002407 (0.0006234)	–0.0006458 (0.0016309)	–0.0008577 (0.0011134)	–0.0010604 (0.0006667)	–0.001229*** (0.0004492)	–0.001372** (0.0005434)
GEE	0.0001896 (0.0007274)	–0.0000754 (0.0006308)	0.0003111 (0.0016507)	0.0002448 (0.0011269)	0.0001813 (0.0006746)	0.0001282*** (0.0004545)	0.0000837 (0.0005499)
PVE	0.0026487 (0.0037086)	–0.0007901 (0.0032164)	0.0039228 (0.0084147)	0.0032274 (0.0057447)	0.0025623 (0.0034394)	0.0020062 (0.0023175)	0.0015395 (0.0028034)
Cons	0.0078669 (0.0536362)	0.0073393 (0.0465166)	–0.0039682 (0.121765)	0.0024916 (0.0831203)	0.0086694 (0.049752)	0.0138351 (0.0335181)	0.0181708 (0.0405543)
Number of observations	1008	1008	1008	1008	1008	1008	1008

Notes: The robust standard errors in parentheses. The statistical significance levels are as follows: *** at the 0.01 level, ** at the 0.05 level, and * at the 0.10 level.

Source: own calculations.

the fourth quantile demonstrates the importance of targeted investments in education for driving human development. This result underscores the need for a strategic allocation of resources to maximise the developmental impact of education spending. Together, these findings emphasise the complexity of human development in SSA (Table 2).

Figure 1 presents a graphical illustration of the results obtained from the panel quantile regression. Shaded areas represent the 95% confidence intervals for the estimates from quantile regression. The vertical axis displays the coefficients of the independent variables.

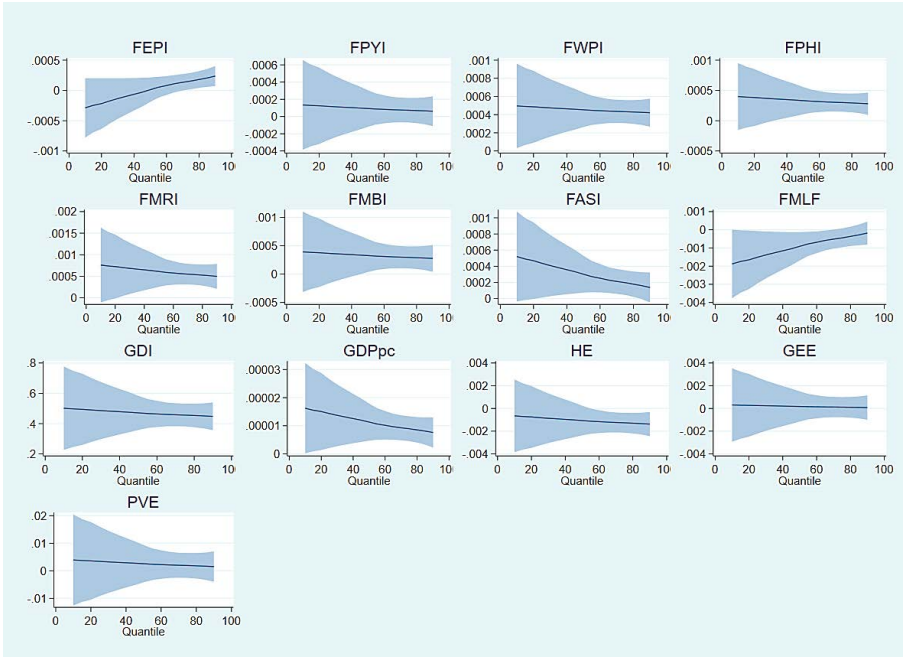

Figure 1. Quantile estimation on HDI

Note: Shaded areas represent 95% confidence intervals.

Source: own calculations.

Koenker and Bassett (1982) recommend using the Wald test to verify the equality of coefficients across quantiles. Based on the Wald test results (see Table 3), it is not possible to reject the null hypothesis of equality at the 5% level of significance for all the independent variables. The null hypothesis (H0) assumes that the effect of women's economic empowerment on human development is consistent across different quantiles of human development distribution in sub-Saharan African countries. This implies that the independent variables have a uniform impact on human development outcomes, regardless of a country's current level of development. The correctness of H0 suggests

Table 3. Wald test of homogeneity of the coefficients

	0.10				0.30			0.50		0.70
	0.30	**0.50**	**0.70**	**0.90**	**0.50**	**0.70**	**0.90**	**0.70**	**0.90**	**0.90**
FEPI	3.26 (0.0709)	3.30 (0.0693)	3.31 (0.0687)	3.32 (0.0686)	3.27 (0.0707)	3.30 (0.0692)	3.31 (0.0689)	3.26 (0.0711)	3.29 (0.0697)	3.25 (0.0712)
FPYI	0.06 (0.8117)	0.06 (0.8116)	0.06 (0.8116)	0.06 (0.8116)	0.06 (0.8116)	0.06 (0.8116)	0.06 (0.8116)	0.06 (0.8117)	0.06 (0.8116)	0.06 (0.8117)
FWPI	0.08 (0.7836)	0.08 (0.7836)	0.08 (0.7836)	0.08 (0.7836)	0.08 (0.7836)	0.08 (0.7836)	0.08 (0.7836)	0.08 (0.7836)	0.08 (0.7836)	0.08 (0.7836)
FPHI	0.13 (0.7147)	0.13 (0.7146)	0.13 (0.7146)	0.13 (0.7146)	0.13 (0.7147)	0.13 (0.7146)	0.13 (0.7146)	0.13 (0.7147)	0.13 (0.7146)	0.13 (0.7147)
FMRI	0.26 (0.6083)	0.26 (0.6081)	0.26 (0.6081)	0.26 (0.6081)	0.26 (0.6083)	0.26 (0.6081)	0.26 (0.6081)	0.26 (0.6083)	0.26 (0.6082)	0.26 (0.6083)
FMBI	0.08 (0.7805)	0.08 (0.7805)	0.08 (0.7805)	0.08 (0.7805)	0.08 (0.7805)	0.08 (0.7805)	0.08 (0.7805)	0.08 (0.7805)	0.08 (0.7805)	0.08 (0.7805)
FASI	1.36 (0.2428)	1.37 (0.2417)	1.37 (0.2413)	1.37 (0.2412)	1.37 (0.2427)	1.37 (0.2416)	1.37 (0.2414)	1.36 (0.2430)	1.37 (0.2420)	1.36 (0.2430)
FMLF	2.32 (0.1276)	2.34 (0.1261)	2.35 (0.1255)	2.35 (0.1254)	2.32 (0.1275)	2.34 (0.1261)	2.34 (0.1257)	2.32 (0.1279)	2.34 (0.1265)	2.32 (0.1279)
GDI	0.11 (0.7407)	0.11 (0.7406)	0.11 (0.7406)	0.11 (0.7406)	0.11 (0.7406)	0.11 (0.7406)	0.11 (0.7406)	0.11 (0.7407)	0.11 (0.7406)	0.11 (0.7407)
GDPpc	0.83 (0.3617)	0.83 (0.3611)	0.83 (0.3609)	0.84 (0.3608)	0.83 (0.3619)	0.83 (0.3612)	0.83 (0.3610)	0.83 (0.3620)	0.83 (0.3613)	0.83 (0.3618)
HE	0.15 (0.6994)	0.15 (0.6993)	0.15 (0.6993)	0.15 (0.6993)	0.15 (0.6994)	0.15 (0.6993)	0.15 (0.6993)	0.15 (0.6994)	0.15 (0.6993)	0.15 (0.6994)
GEE	0.01 (0.9049)	0.01 (0.9049)	0.01 (0.9049)	0.01 (0.9049)	0.01 (0.9049)	0.01 (0.9049)	0.01 (0.9049)	0.01 (0.9049)	0.01 (0.9049)	0.01 (0.9049)
PVE	0.06 (0.8059)	0.06 (0.8059)	0.06 (0.8059)	0.06 (0.8059)	0.06 (0.8059)	0.06 (0.8059)	0.06 (0.8059)	0.06 (0.8059)	0.06 (0.8059)	0.06 (0.8059)

Note: The numbers in parentheses are p-values.

Source: own calculations.

that policies aimed at empowering women economically could have similar effects across countries in the region, irrespective of their position in the human development spectrum. The shared developmental challenges, similar policy environments, and comparable responses to women's empowerment interventions across sub-Saharan Africa could explain this uniformity. However, it is important to note that failing to reject H0 does not necessarily mean the effects are identical across all quantiles, but rather that any differences are not statistically significant enough to warrant rejection of the null hypothesis.

The Wald test results enhance the reliability of our quantile regression analysis by demonstrating stability in the relationship between women's economic empowerment indicators and human development outcomes across different levels of development in SSA. This aligns with Machado and Silva's (2019) methodological framework for panel quantile regression, which emphasises stable patterns across the conditional distribution rather than specific segments driving observed relationships. The stability of coefficients across quantiles has significant policy implications, suggesting that interventions aimed at empowering women economically can yield consistent benefits, irrespective of a country's development level. This finding contributes to the broader literature by offering evidence for the applicability and effectiveness of women's economic empowerment initiatives across diverse developmental contexts within SSA.

4. Discussion

Women's entrepreneurship in SSA plays a crucial role in driving social transformation, alleviating poverty, and fostering economic growth, ultimately contributing to improved human development. This study's findings align with the perspective that female entrepreneurship serves as a powerful tool for women's empowerment, challenging established social and cultural norms while promoting economic independence. The research highlights the complex interplay between entrepreneurial success and the socio-cultural environment in Africa, where female entrepreneurs often demonstrate remarkable resourcefulness by leveraging social networks to navigate resource-constrained settings. However, the study also acknowledges the persistent hurdles faced by women entrepreneurs in Africa, including limited access to resources and enduring socio-political constraints. These findings contribute to the ongoing discourse on the transformative potential of female entrepreneurship in developing economies, as explored by Haugh and Talwar (2016). Additionally, they complement the work of Ojong et al. (2021) on the importance of social networks and adaptive strategies for women entrepreneurs in Africa. The

study's recognition of persistent challenges aligns with the observations made by Jaiyeola and Adeyeye (2021) regarding the obstacles to women's economic advancement in the region. Furthermore, the research supports the notion that targeted interventions can be highly effective in fostering enterprise growth, even in less developed areas, as demonstrated by Campos et al. (2018).

The study's findings on women's workplace in SSA align with and expand upon existing research on the topic. Flores et al. (2021), who emphasise the importance of job quality, labour empowerment, and workplace atmosphere, support this perspective. The study's findings also resonate with Monteiro et al. (2021), who highlight the significance of supportive work environments and women's inclusion in managerial roles for overall corporate performance and social responsibility. Additionally, the research aligns with Ketchiwou and Dzansi (2023) in recognising the detrimental effects of gender discrimination on women's career prospects and overall work performance. The study's emphasis on addressing women's needs in the workplace for improved job engagement and performance is consistent with the findings of Wafa et al. (2023), further underscoring the multifaceted nature of women's economic empowerment and its impact on human development in SSA.

This study's findings on marriage rights and parenthood policies in SSA reveal their fundamental role in promoting human development. The research aligns with Doss, Summerfield et al. (2014), regarding the importance of secure property rights within marriage for women's empowerment and household welfare. The study's results complement Delprato and Akyeampong's (2017) research on the educational benefits of delayed marriage, while also supporting Marphatia (2017) observations about the health implications of early marriage. In terms of parenthood's impact, the study's conclusions mirror Kabeer's (2018) in East Africa. The findings also support Bongaarts (2020) research on the relationship between women's education, family planning, and development outcomes, highlighting how supportive parenthood policies contribute to broader societal advancement through improved health outcomes, educational investments, and economic stability.

The study's findings on the GDI's positive impact across all quantiles in SSA demonstrate the fundamental importance of gender equality in driving human development. This comprehensive relationship aligns with Sen's (1999) foundational work on development as freedom and expands upon Kabeer's (2020) intersectional approach to understanding gender dynamics. The research reveals how gender equality improvements lead to widespread positive outcomes across multiple sectors, including health, education, finance, and agriculture, supporting the findings of Taukobong et al. (2016). Furthermore, the findings reinforce Manandhar et al.'s (2018) research on the interconnection between gender equality and the Sustainable Development Goals, particularly regarding how improved education and economic opportunities for women contribute to better health outcomes and overall societal welfare.

Women's mobility emerges as a crucial factor in advancing human development in SSA through multiple pathways, including enhanced economic participation, improved health outcomes, and overall well-being. The study's findings align with Porter's (2011) research on the fundamental role of mobility in women's economic emancipation, while extending beyond traditional mobility concepts to include technological innovations. The study's results also complement Taukobong et al.'s (2016) work on the relationship between mobility and health outcomes, while reinforcing Guli and Geda's (2021) findings on how improved infrastructure and mobility enhance women's labour market participation and family welfare.

The study reveals that women's assets have a significant positive impact on human development in SSA, supporting Doss, Kovarik et al.'s (2015) research on the critical role of women's property rights in development outcomes. The findings extend beyond Jones et al.'s (2020) work by demonstrating how women's economic resources and decision-making capabilities contribute to broader development indicators, not just nutritional outcomes. The research also builds upon Deere and Doss's (2006) concept of the "gender asset gap" by revealing a more nuanced relationship between asset ownership and development. Furthermore, this research links to Asaleye and Strydom's (2023) analysis of empowerment and development dynamics, showing how women's ownership of assets interacts with different social and economic factors to affect human development in the region.

The study's findings reveal a complex relationship between female labour force participation and human development in SSA, challenging conventional assumptions about women's employment and development outcomes. This research also aligns with Kabeer's (2016) analysis regarding the prevalence of low-quality, informal employment that fails to meaningfully contribute to household welfare or economic growth. The study's findings support Duflo's (2012) emphasis on the importance of job quality and supportive policies in realising the benefits of women's labour participation. Finally, these results particularly align with Thaddeus et al.'s (2022) perspective, which suggests that female labour force participation may constitute a liability rather than an asset for economic development in SSA.

Conclusions

The purpose of this study was to investigate the impact of WEE on human development in the SSA, employing a panel quantile regression approach. Our results offer several revelations. As shown by the different effects across quantiles for many indicators, WEE has different effects on human develop-

ment depending on different levels of development. Female entrepreneurship (FEPI) exhibits a threshold effect; it becomes important only at more developed levels. This implies that encouraging female entrepreneurship could need some degree of institutional and financial growth to noticeably affect human development.

Consistently showing positive effects across all development levels, workplace participation and marriage rights highlight their basic relevance for human development in the region. By reiterating the important contribution of general gender equality in promoting human development, the Gender Development Index shows a strong positive influence across all quantiles. Though there are some variances, indicating the complex interaction between these elements and larger social settings, parenting rights and mobility show positive impacts at most levels.

These findings contribute to the growing body of knowledge on WEE and development in SAA by providing a more complex picture of how several facets of empowerment affect human development at various levels of development. They emphasise the need for tailored policy approaches, taking into account the unique development situation of each nation or region. Our studies also emphasise the need to use intersectional and context-specific strategies in the design of treatments meant to advance WEE and human growth. One-size-fits-all policies might not be efficient across all development levels, as the different impacts across quantiles indicate.

Future studies should investigate the processes behind these different effects, including qualitative studies to offer a more in-depth understanding of the experiences of women in several development environments. Furthermore, looking at the long-term effects of particular empowerment initiatives could provide policymakers with important guidance.

Our research highlights the complexity of this link, even as it validates the general favourable impact of WEE on human development in the SAA. We should carefully customise policies meant to empower women to local conditions and development levels as the area continues to strive towards the Sustainable Development Goals to maximise their influence on general human development.

Appendix

Table A1. Descriptive statistics

Variable	Number of observations	Mean	Standard deviation	Min	Max
HDI	1008	0.4971657	0.1027258	0.26	0.806
FEPI	1008	71.55258	22.96635	0	100
FPYI	1008	55.62996	28.70812	0	100
FWPI	1008	61.18552	34.36917	0	100
FPHI	1008	40.01984	24.8371	0	80
FMRI	1008	59.74206	29.22931	0	100
FMBI	1008	79.86111	22.7226	0	100
FASI	1008	68.88889	28.06496	0	100
FMLF	1008	77.43058	16.72117	27.988	106.694
GDI	1008	0.8814048	0.0671612	0.632	1.019
GDPpc	1008	1879.743	2240.003	255.1003	14222.55
HE	1008	5.331658	3.058171	1.1072	34.40539
GEE	1008	3.873901	2.099578	0.4505197	14.75839
PVE	1008	–0.5058015	0.8680485	–2.847852	1.2236

Source: own calculations.

Table A2. Correlation matrix

	FEPI	FPYI	FWPI	FPHI	FMRI	FMBI	FASI	FMLF	GDI	GDPpc	HE	GEE	PVE
FEPI	1.000												
FPYI	0.027	1.000											
FWPI	0.317	0.452	1.000										
FPHI	–0.01	–0.15	0.059	1.000									
FMRI	0.239	0.418	0.578	–0.36	1.000								
FMBI	0.117	0.302	0.300	–0.11	0.247	1.000							
FASI	0.371	–0.001	0.271	–0.01	0.365	0.021	1.000						
FMLF	–0.12	0.077	0.016	–0.10	0.268	–0.23	0.304	1.000					
GDI	0.216	0.144	0.113	–0.02	0.191	0.004	0.333	0.224	1.000				
GDPpc	–0.11	0.064	–0.17	0.133	–0.11	–0.03	0.128	–0.13	0.323	1.000			
HE	0.179	0.138	0.091	0.115	0.139	0.053	0.244	–0.01	0.168	–0.11	1.000		
GEE	–0.06	–0.01	0.026	0.007	0.098	–0.03	0.024	–0.06	0.247	0.175	–0.28	1.000	
PVE	0.09	0.083	–0.09	–0.08	0.094	0.009	0.123	–0.10	0.321	0.427	0.04	0.280	1.000

Source: own calculations.

Table A3. VIF for independent variables

Variable	VIF	Tolerance
FMRI	2.49	0.402009
FWPI	2.34	0.427591
FASI	1.81	0.552489
FMLF	1.78	0.560930
GDPpc	1.72	0.581145
FPYI	1.63	0.612757
GDI	1.63	0.613298
FEPI	1.52	0.657848
PVE	1.46	0.683914
FPHI	1.40	0.712004
GEE	1.38	0.723878
HE	1.37	0.730959
FMBI	1.29	0.773770

Source: own calculations.

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The effects of COVID-19 on Polish enterprises

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Abstract

The COVID-19 pandemic had massive impacts on economic sectors. This paper explores the economic effects of COVID-19 on 150,000 Polish enterprises. The paper analyses financial data from the Polish National Court Register and explores heterogenous impacts brought by the COVID-19 pandemic across multiple sectors. Its innovative contribution lies in adopting a granular perspective to assess the sector-specific impacts of COVID-19. This approach distinguishes the paper from much of the existing literature, which predominantly emphasises global or macroeconomic outcomes. The paper compares financial ratios across 2019 and 2020, applying Wilcoxon and Mann-Whitney tests to measure changes in profitability, liquidity, working capital, and leverage ratios. Key findings indicate a disparity in revenues across sectors, with some showing resilience in adapting to pandemic-induced challenges. The analysis reveals that 28 PKD divisions experienced significant revenue reductions (up to −70% in tourism-related sectors), while 25 divisions experienced gains (up to +23% in Information Technology sectors). Notably, while working capital metrics deteriorated across most sectors, with Days Receivables Outstanding increasing substantially, liquidity ratios improve across 80% of sectors.

Keywords

- COVID-19
- economic sectors
- Wilcoxon test

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Introduction

The short-term impact of COVID-19 on businesses was largely predictable yet uncontrollable. Fear of infection led to substantial reductions in labour supply and demand in positions where infection probability is highest, and comparatively smaller reductions in positions that are less at risk. Throughout history, the threat of pandemics has been readily apparent due to the cyclical nature of these virus subtypes, which reoccur every 10–50 years (Potter, 2001). The daily number of confirmed COVID-19 cases in Poland and the U.S. is presented in Figure 1.

The business landscape has experienced substantial disruption through pandemics, as consumers focus on immediate personal safety through unsustainable actions (Funk et al., 2009). The retail and hospitality sectors faced severe downturns due to lockdowns and reduced consumer spending. These sectors also have high exposure to domestic and foreign customers compared to other sectors, increasing the potential for exposure (Lam et al., 2004). The COVID-19 pandemic primarily harmed small and medium-sized enterprises (SME) through reduced liquidity and the need for redundancies (Bartik et al., 2020; Fairlie, 2020; Lalinsky & Pál, 2022). The government sought to limit damages by offering aid to microenterprises based on monthly revenue decline. However, the liquidity provided through Polish programmes went to businesses that were too severely affected to be rescued and business enti-

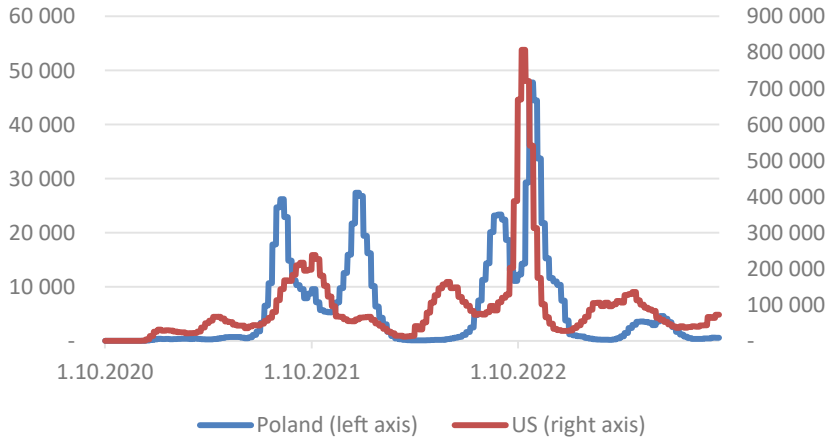

Figure 1. Daily new confirmed cases due to COVID-19 (rolling 7-day average)

Source: (https://ourworldindata.org/covid-cases).

ties that did not require such support (Kochaniak et al., 2023). The technology and e-commerce sectors saw unexpected growth.

By analysing a comprehensive dataset, this study provides a detailed and nuanced understanding of the heterogeneous effects of the pandemic on various sectors within a single country. The novel aspect of this research lies in its granular approach to examining sector-specific impacts of COVID-19. Thus, this paper sets itself apart from the reviewed literature, most of which focuses on global or macroeconomic effects. The in-depth analysis in this paper regarding financial ratios, such as profitability, liquidity, working capital, and financial leverage across different sectors provides a unique perspective on the varying degrees of vulnerability and resilience exhibited during the pandemic. Moreover, this study emphasises the role of government intervention, particularly the 'Anti-Crisis Shields' regulations implemented by the Polish government, thus adding a new dimension to the understanding of how targeted policy measures can help mitigate the adverse effects of the COVID-19 pandemic on specific sectors.

An important aspect is the ability of the global economy to adjust relatively quickly to fast-changing, severe conditions, facilitated both by governmental actions and company agility (Korneta & Rostek, 2021). The combination of an effective governmental response, e.g., economic stimulus packages, and the adaptability of businesses through innovation and restructuring may reduce the negative impacts of global crises such as pandemics, earthquakes, eruption of wars, etc. The ability of economies to bounce back under extreme circumstances highlights the resilience that can be fostered through targeted interventions and flexible business strategies (Korneta & Rostek, 2021).

Thus, by providing a detailed account of the specific measures employed, including subsidies, loan guarantees, tax deferrals, and exemptions, this study offers valuable insights into the effectiveness of these government policies in stabilizing affected industries, and in facilitating a resilient recovery. The integrative value of this research lies in its ability to bridge various strands of literature, including studies on macroeconomic effects, policy responses, supply chain disruptions, and sectoral dynamics. By incorporating insights from these diverse areas, the paper provides a comprehensive, holistic understanding of COVID-19's impact on the Polish economy.

This paper is significant due to the fact that we assess 150,000 companies in Poland, thus extending the international analysis of COVID-19 to this country. This is the first study that uses Polish data with a vast quantity of business classification (PKD) codes, covering many heterogeneous companies. Moreover, this paper studies macroeconomic governmental policies in addition to a microeconomic analysis of different sectors of the economy. As a country with a population of nearly 40 million, Poland is a key growing economy at the heart of the European Union.

The remainder of the paper is organised as follows: Section 1 reviews the literature; Section 2 presents the data and methodology; Section 3 presents and discusses the empirical findings; and last Section offers conclusions.

1. Literature review

This section reviews some recent papers dealing with the effects of COVID-19.

Raza (2023) and McKibbin et al. (2023) highlight the importance of coordinated fiscal and monetary policies in mitigating the adverse effects of the pandemic on prices, output, and GDP. Alon et al. (2023) find that emerging markets experienced larger output losses and greater fatalities compared to advanced and low-income economies, due to factors such as employment in high-contact occupations and limited public transfers. This study extends the analysis to Poland, an economy that experienced relatively higher growth as compared to the emerging markets studied by Alon et al. (2023).

Several studies focus on the pandemic's impact on specific sectors. Karaki et al. (2023) examine the role of consumer pessimism in amplifying financial uncertainty shocks across American industrial sectors. Nyakurukwa and Seetharam (2023) analyse the interconnectedness of sectors within the Johannesburg Stock Exchange, finding increased integration during the pandemic. McCann et al. (2023) and Basurto et al. (2023) assess the effectiveness of various policy measures in supporting economic recovery. McCann et al. (2023) emphasise the importance of providing liquidity finance to viable firms in Ireland, while Basurto et al. (2023) find that continuous mild lockdowns or lighter restrictions are more effective than alternating between strict lockdowns and complete reopenings. Guedegbe (2022) investigates the effects of COVID-19 policy responses on Nigerian agricultural households, highlighting the need to consider farm viability when designing containment measures.

Kyriazis et al. (2023) examine the hedging effectiveness of traditional stock indices, precious metals, and cryptocurrencies during the pandemic. J. Wang et al. (2023) measure the COVID-19 spillover impact on monetary policy transmission and business practices in Asian financial markets. Kazancoglu et al. (2023) examine the sector-specific impacts of the pandemic on global supply chains, focusing on Turkey and China, and emphasise the importance of governmental and managerial interventions in mitigating negative effects.

Ikhsan and Amri (2023) investigate the moderating role of the COVID-19 pandemic on the relationship between bank credit and sectoral output growth in Indonesia. X. Wang (2023) and Archanskaia et al. (2023) discuss the pandemic's adverse effects on corporate sectors globally and assess corporate financial distress in the European Union.

The following studies analyse the effect of COVID on employment in Poland. Kwiatkowski and Szymanska (2022) analyse changes in employment and their determinants in twenty sectors of economic activity in Poland during the COVID-19 pandemic. The study focuses on the direct short-run employment effects. Their results suggest that employment was affected by a realloca-

tion shock—a decrease in employment that occurred in some sectors (e.g., arts, entertainment and recreation) was associated with an increase in other sectors (e.g., human health and social work activities). The paper by Bartosik (2024) investigates changes in employment across groups of workers during the coronavirus pandemic in Poland. It analyses the impact of the coronavirus crisis on employment by comparing actual and predicted employment growth during the pandemic period, using Okun's law. The outcome of research indicates that the total employment response to output change was relatively small, compared to the historical pattern. However, the response was unequal across groups of workers. The youngest workers, particularly women, and those with temporary employment contracts were most affected by the pandemic.

The reviewed literature reveals a noticeable lack of sector-specific studies utilising big data to analyse the impact of COVID-19 on the Polish economy during the pandemic in 2022.

2. Research methods

2.1. Data

The financial data of private companies are stored at the Polish National Court Register (KRS) in Poland's Ministry of Justice. The financial accounts contain Balance Sheets and Profit and Loss Statements, but not Cash Flow Statements. These data are publicly available. However, it is possible to access only one company's data per download. The database used in this study includes more than 150,000 such individual records, and the company Notoria Serwis S.A. provides this dataset. For each company, the data contain business classification (PKD) codes. PKD is the hierarchical classification system of the social-economic activities carried out by economic entities.

Each company reports its main PKD code used in this paper. The current version of the PKD system is PKD 2007, which is fully coherent and comparable with the classification NACE Revision 2 in methodology, concept, scope and coding (up to the fourth digit). NACE (Nomenclature statistique des Activités économiques dans la Communauté Européenne) is the Statistical Classification of Economic Activities in the European Community established by the Council Regulation No 3037/90 of October 9th, 1990 (OJ No L 293 of Oct. 24th 1990). The current version is Revision 2 (Regulation (EC) No 1893/2006). It is the European implementation of the United Nations International Standard Industrial Classification of All Economic Activities (ISIC), Revision 4, consistent with the North American Industry Classification System

The PKD classification uses four-digit hierarchical levels, which include 21 sections, 88 divisions, 272 groups, and 615 classes. This paper uses divisions, since they are general but not too small to perform statistical testing. Furthermore, we eliminate 10 divisions with fewer than 30 companies in order to improve the statistical significance of the results. The 3 divisions which belong to the "Financial and insurance activities" section are omitted, as banks, trusts, insurance companies, and pension funds have different financial reporting standards. Thus, the majority of financial ratios investigated in this paper cannot be computed effectively. For example, in the financial reports of banks, insurance companies, etc., such positions as inventories, receivables, and payables (generally trade receivables) cannot be found.

Financial ratios for fiscal years 2019 and 2020 are compared to examine the effects of the COVID-19 pandemic. The pandemic reached Poland at the beginning of March 2020. During the period of the pandemic, some measures were implemented, such as social distancing, travel restrictions, and several national lockdowns, including closing schools, non-essential shops, and cultural institutions. These restrictions severely impacted the business activities of some enterprises, whereas they boosted sales and profits in others. The purpose of this article is to provide quantitative data on which sectors were affected and to what extent. Consequently, the paper has broader policy implications regarding other low-frequency, high-risk events.

This research considers only companies that reported financial data for 2019 and 2020, enabling the derivation of various operating and financial ratios. 155,410 companies are covered, which are classified into 75 divisions of PKD.

While the study relies on data including all registered companies required to report financial statements, potential selection bias may exist, since some sectors are excluded from analysis due to the small number of companies operating in them. The dataset only includes companies that survived and reported data for both 2019 and 2020, thereby potentially excluding firms that failed during the pandemic, which could underestimate the negative impacts (survivorship bias). Furthermore, larger companies typically have more comprehensive reporting requirements and resources for financial reporting, potentially leading to overrepresentation of larger firms and underrepresentation of smaller enterprises (size bias).

2.2. Financial ratios

Alongside Revenues from Sales (RS), which is the primary financial variable affected by COVID-19, we consider several other financial ratios selected from the following four categories: (1) profitability, (2) liquidity, (3) working capital, and (4) financial leverage, thus providing a comprehensive financial outlook of

the companies. These categories are similar to those used by Gunasekaran et al. (1995) and Kallunki et al. (1996), excluding the category (5), detailed cash flow positions, as these are not available for private companies, which were not obliged to report a detailed Cash Flow Statement.

The chosen ratios are the following: (1) profitability ratios: R1—Operating Profit Margin, R2—Return on Assets, (2) liquidity ratios: R3—Quick Ratio, R4—Cash Ratio, (3) working capital ratios are presented as: R5—Cash Conversion Cycle, R6—Days Receivables Outstanding, R7—Days Inventory Outstanding, R8—Days Payable Outstanding, and (4) financial leverage ratios: R9—Debt Ratio, R10—Interest Coverage Ratio. Appendix I provides the definitions of each ratio. Revenues from Sales (RS), and ratios R1, R2, R3, R4, R8, and R10, are called concordant ratios because their increases imply strengthening the financial position of a company. The ratios R5, R6, R7, and R9 are called discordant ratios because their increases indicate a worsening of a company's financial position.

2.3. The statistical test

To assess the statistical significance of variations in Revenues from Sales and financial ratios between the pre-pandemic year of 2019 and the first pandemic year of 2020, the paper uses the nonparametric one-sided Wilcoxon test (Wilcoxon, 1945). This test serves as a paired difference test for two matched samples i.e., observations for the same company from two consecutive years. It is crucial to note that this test does not require specific assumptions about a probability distribution, apart from the symmetricity of the differences and independence of them. Symmetrical distribution of differences means that the distribution of the differences between paired observations should be balanced around the means. The assumption of difference independence is satisfied when paired observations are randomly and independently drawn.

The Wilcoxon test was chosen because it is particularly suitable for comparing paired financial observations from the same companies across two time periods, while making minimal distributional assumptions, requiring only symmetry of differences rather than normality of the underlying data—a crucial consideration given the well documented non-normal nature of financial ratios discussed in financial literature. Let X_i^{2019}, X_i^{2020} be a pair of the same financial variable realisation for i-th company drawn from the joint distribution (X^{2019}, X^{2020}) in two consecutive years 2019 and 2020. The following hypotheses are tested:

$$H_0 : \begin{cases} X^{2019} < X^{2020} \text{ and } X \text{ is concordant variable} \\ X^{2019} \geq X^{2020} \text{ and } X \text{ is discordant variable} \end{cases} \quad (1)$$

and

$$H_1 : \begin{cases} X^{2019} \geq X^{2020} \text{ and } X \text{ is concordant variable} \\ X^{2019} < X^{2020} \text{ and } X \text{ is discordant variable} \end{cases} \quad (2)$$

These hypotheses are tested at the 0.05 significance level. Hence, the result for a given financial variable, and a PKD division, can be represented as an output variable (O) that can be defined as:

$$O = \begin{cases} 1 & \text{if} \quad H_0 \text{ is rejected} \\ -1 & \text{if} \quad H_1 \text{ is rejected} \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

The output variable equals 1 if we observe a statistically significant positive change in this variable. If the output variable is equal to –1, a statistically significant negative change occurs. In other cases, the output equals zero. Table 1 presents the output table for all financial variables and PKD divisions. All statistical tests in this paper are calculated using the SciPy library in Python.

3. Results

3.1. Empirical findings and discussion

In 2020, the Polish government implemented several measures to provide liquidity and support businesses during the economic downturn caused by the COVID-19 pandemic. It provided the following liquidity facilities, known as Anti-Crisis Shields:

a. Subsidies for salaries and social security contributions: This helped companies retain employees and avoid layoffs. Regardless of their size, businesses could apply for a three-month subsidy in case of work stoppages or reduced working time. This subsidy covered social insurance contributions, ranging from 50% to 90% of the minimum wage for each employee, depending on the recorded decrease in turnover in 2020; for micro firms with up to 9 employees, social insurance contributions were covered by the budget for three months. For companies employing from 10 to 49 employees, 50% of social insurance contributions are paid by the government budget. The self-employed and also employees working on civil-law contracts were eligible for a one-time benefit. During the pandemic, there was an exemption from social security contributions for industries affected by the restrictions.

b. Loan guarantees: Through the National Economy Bank (BGK in Polish), the government guarantees loans issued by commercial banks to small-, medium-sized, and large businesses. This encouraged banks to lend by mitigating their risk.
c. Direct loans: The Polish Development Fund (PFR in Polish) also offered direct loans to many enterprises which could be partially written off. Even up to 70% of the financing was non-returnable upon fulfilling the relevant conditions related to maintaining employment, and continuing business activity, and the level of lost sales was substantial.
d. Deferral of tax payments: Businesses could postpone paying various taxes, including income tax, Value Added Tax (VAT), and social security contributions, offering temporary cash flow relief.
e. Tax exemptions: Certain sectors, such as hospitality and entertainment, received temporary exemptions from specific taxes.
f. Moratorium on loan repayments: The government implemented a temporary moratorium on loan repayments to banks for some businesses and private individuals facing COVID-19-related financial hardship, allowing them to request a loan repayment suspension from their respective lenders. However, a nationwide moratorium on all loan repayments was not introduced, since they could be chosen by the enterprises that needed this help. Although the interest accrued, increasing the gross value of loans, it did not have to be paid.
g. The most seriously hit country received specialised additional help from the government, which was approved by the European Commission and discussed later in the article.

Determining the exact amount of liquidity provided by the Polish government is challenging, due to the diverse nature of the support measures. However, estimates suggest that the total value of financial aid offered through various programs exceeded PLN 200 billion (approximately €45 bn) in 2020. It is noteworthy that this figure does not represent the actual amount utilized by businesses, as some companies might not have needed to use the full extent of available support. This aid was offered largely through the establishment of the COVID fund, dedicated to combating the negative impact of the pandemic and with a balance sheet size of PLN 100 bn. The fund was supervised by the Prime Minister but flows from the fund would be transferred to various ministers and other institutions involved in combating the negative consequences of the pandemic. Revenues were raised through BGK's bond issues.

As a consequence of various fiscal stimuli and a lower inflow of taxes, the government budget deficit soared to 6.9% of GDP, according to the European Union standards (ESA methodology). As a response to COVID-19, the reference policy rate of the National Bank of Poland (NBP) was lowered from 150 bps to an all-time low of 10 bps, significantly reducing the financial costs for en-

terprises. The NBP provided liquidity to banks, reduced the required reserve ratio from 3.5% to 0.5%, and changed the interest rate on required reserves to a level equal to the policy interest rate. The NBP also purchased Polish Treasury and government-guaranteed securities on the secondary market of 135.8 bn (5.8% of 2020 GDP). Additionally, the Polish Financial Supervisory Authority (PFSA) announced measures to grant banks some flexibility to meet capital and liquidity requirements.

According to Dębkowska et al. (2021), 86% of the surveyed entrepreneurs utilised the solutions provided by the Anti-Crisis Shield. Companies widely leveraged the range of available support instruments, often using several complementary tools simultaneously. State aid was rated, on average, 3.5 on a scale of 1 to 5. Ambroziak's (2022) paper aims to identify and initially assess the implementation of schemes under COVID-19-related state aid was granted in Poland for different instruments and beneficiary sizes. The study helped demonstrate how Polish aid schemes assisted mainly micro- and small-sized companies, which usually suffered from poor liquidity, by means of predominantly soft instruments.

Table 1 presents the variable values for financial ratios across the top 10 and lowest 10 PKD divisions. Appendix 3 provides a table with all PKD divisions. Additionally, to facilitate the analysis, rows in the table, i.e. PKD divisions, were sorted according to a change in variable Revenues from Sales (RS) between 2019 and 2020.

Table 1. The output table, first and last 10 sectors affected by COVID-19

PKD	d% RS	RS	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
79	–70	–1	–1	–1	–1	0	–1	–1	0	1	–1	–1
51	–55	–1	0	0	0	1	–1	–1	0	0	0	0
90	–46	–1	–1	–1	0	0	–1	–1	0	1	–1	–1
55	–39	–1	–1	–1	–1	0	–1	–1	0	1	–1	–1
56	–24	–1	–1	–1	–1	–1	–1	–1	–1	1	–1	0
91	–18	–1	–1	–1	–1	0	–1	–1	0	0	–1	0
93	–16	–1	–1	–1	0	1	–1	–1	0	1	–1	0
15	–14	–1	0	0	1	1	–1	–1	–1	0	0	0
60	–13	0	0	0	0	1	0	0	0	0	0	0
94	–13	–1	0	0	0	1	–1	–1	0	0	0	0
…												
21	8	1	1	1	0	1	0	0	–1	0	0	0

table 1 continued

PKD	d% RS	RS	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
03	8	1	0	0	1	1	0	0	0	0	1	0
63	8	1	1	0	1	1	–1	–1	0	0	0	0
59	10	–1	0	–1	0	0	–1	–1	0	1	–1	0
84	10	0	0	0	1	0	0	–1	0	1	0	0
38	17	1	1	1	1	1	–1	–1	0	0	1	1
75	19	1	0	0	1	1	–1	–1	0	0	0	0
95	20	0	0	0	0	0	–1	–1	0	0	0	0
27	21	0	1	0	0	1	–1	0	–1	1	0	1
62	23	1	1	0	1	1	–1	–1	0	0	1	0

Source: own calculations.

There are a few general observations that can be drawn from Table 1. First, the effect of the pandemic on Revenues from Sales (RS) was mixed across the economy—in 28 PKD divisions, enterprises recorded a significant reduction in sales, in 22 divisions sales did not change statistically significantly, and for 25 divisions, sales improved to a significant degree. These outcomes are based on the quantity of divisions, not on the volume of goods and services they generate. The behaviour of profitability ratios, i.e. Operating Profit Margin (R1), and Return on Asset (R2) are naturally positively correlated with the change of Revenues from Sales (RS). However, one observes that Operating Profit Margin (R1) does not drop as significantly as Revenues from Sales (RS). The reason is that part of anti-crisis aid, discussed later in detail, is recorded as "Other operational profits" in the Profit and Loss statement.

Second, in almost all divisions, Days Receivables Outstanding (R6) deteriorated as enterprises decided to delay paying their trade receivables during the pandemic. Days Inventory Outstanding (R7) worsened as well, albeit in a smaller number of PKD divisions. It is worth noting that in most cases, when a drop in sales occurred in enterprises, their vendors spontaneously decided to extend the term of payables, as is indicated by an increase of the variable Days Payable Outstanding (R8). Despite this, the overall Cash Conversion Cycle (R5) worsened across almost all divisions.

Third, regardless of the worsening cash conversion, which might naturally lead to lowering liquidity, overall liquidity, measured by Quick Ratio (R3) and Cash Ratio (R4), substantially increased for almost all PKD divisions. This phenomenon is attributed to a liquidity injection from the Polish government into the economy , as well as other liquidity-improving programs and measures enforced by law.

Finally, the Debt Ratio (R9) increased to a partial degree because of the moratoria on loan repayments, during which interest was accrued and not repaid. At the same time, the Interest Coverage Ratio (R10) did not change significantly for many divisions. This was a result of adjusting financial costs to a drop in operating profits, due to the interest rate being reduced to an all-time low by the National Bank of Poland.

We decided to look in detail into those divisions in which Revenues from Sales either decreased or increased substantially, i.e. above 20%. The divisions in which Revenues from Sales statistically significantly dropped most were as follows: 'Tour operator, middlemen, agents and other reservation service and related activities' (–70.0%), "Air transport" (–55.1%), "Creative, arts and entertainment activities" (–46.4%), "Accommodation" (–38.6%), and "Food and beverage service activities" (–24.2%). The first two are related to a sharp reduction in people's mobility following the start of the pandemic and tourism stopping; the third relates to the closing of theatres, cinemas, and art galleries because of social distancing rules; the fourth (Accommodation) refers to the locking down of hotels and hostels caused by tourism having to stop.[3]

The last division indicates a problem encountered by many restaurants and catering activities to switch from physical meetings with their clients to remote delivery of their products. For these divisions, almost all financial ratios (apart from Days Payable Outstanding for "Accommodation") deteriorated during the first pandemic year, and liquidity ratios did not improve or even deteriorated. The decreases in Revenues from Sales were so dramatic that even liquidity injections by the government did not boost their cash position. Thus, many restaurants and catering enterprises stood on the verge of bankruptcy. Thanks to the special support dedicated to these sectors, which is mentioned below, many enterprises from these sectors survived.

During the pandemic in Poland, the national carrier Polskie Linie Lotnicze LOT S.A. received support under the Support Program. This program was adopted by the Council of Ministers on December 21, 2020, and was intended to enable LOT Polish Airlines to remain on the market in the face of COVID-19. The European Commission's decision on December 22, 2020 approved the support package for PLL LOT, which amounted to PLN 2.9 bn. This support was intended to ensure that the company maintained financial liquidity and an adequate amount of capital necessary to run its business. The program assumed the recapitalization of PLL LOT from the state budget and granted a loan from the Polish Development Fund.

The tourist voucher was launched in Poland as a new form of support for the tourism industry weakened by the COVID-19 pandemic. It was payable regardless of income level and amounted to a one-off amount of PLN 500 (USD 125) for each child up to 18 years of age. Additionally, children with a disabil-

[3] See Osorio et al.'s (2023) study on the vulnerability of the Spanish tourism sector.

ity certificate received one additional benefit in the form of a voucher supplement, also for PLN 500. The voucher could be used to pay for hotel services or tourist events carried out only in Poland. The Polish Tourist Voucher was in the form of an electronic voucher, valid until the end of March 2022.

The Polish Ministry of Culture and National Heritage launched the "Culture Online" program during the COVID-19 pandemic. This support program aimed to help artists, creators, and institutions who, due to the ongoing epidemic, could not pursue their artistic activities in their current form. With a program budget of PLN 80 mln (USD 20 mln), this was an important initiative that helped adapt cultural activities to the new online reality. During the pandemic, the Ministry introduced several other more specialised support programs for the cultural sector: the budget of the "Film Production" program was increased to support film production in Poland; "COVID" subsidies were launched for state cultural institutions; the "Shield for writers" was created. A Cultural Support Fund was also established, an initiative aimed at supporting various fields of culture during the difficult period of the pandemic. Finally, a program was also launched to help artists learn about various solutions that support their activities on the internet.

Overall, the increases in revenues were much smaller than the decreases. The divisions that statistically significantly benefited from the pandemic were "Computer programming, consultancy and related activities" (+23.3%), and "Veterinary activities" (+19.2%). In the first case, the pandemic increased demand for computer consultancy and computer facilities management services due to remote working. The natural productivity of this division was not negatively impacted, since many IT specialists, including programmers, worked remotely prior to the pandemic. In the second case, people who were confined in their homes took greater care of their pets. Interestingly, in both cases, the return on assets did not increase to a statistically significant degree, for two different reasons. In the IT business, this was due to an increase in fixed assets (purchasing new hardware or software) because at the same time the operating profit margin improved. In the "Veterinary activities" division, the operating profit margin did not register a statistically significant change, which implies that operating costs increased at this time. The contrasting performance of operating margins between IT and veterinary services during the pandemic reflects fundamental differences in their business models and operational constraints. The IT sector's improved margins stemmed from its ability to scale services without proportional cost increases, existing remote work infrastructure, and reduced office expenses during lockdowns. In contrast, despite experiencing higher demand from increased pet ownership during lockdowns, veterinary services faced proportionally higher operating costs, owing to necessary safety protocols, protective equipment investments, and facility adaptations for social distancing. Moreover, the physical nature of veterinary work limited scalability and required continued in-person opera-

tions, preventing the cost efficiencies achieved in the IT sector. This explains why increased revenue from veterinary services was offset by higher operational costs, resulting in stable rather than improved margins. However, IT companies could leverage their digital infrastructure to improve profitability.

There are also divisions in which Revenues from Sales increased substantially. However, these increases are not statistically significant. They were "Manufacture of electrical equipment" (+20.9%), and "Repair and maintenance of computers and personal and household goods" (+19.5%). This can be explained by the fact that there were 500 and 200 enterprises registered in these divisions, respectively, but few big players were generating revenues in the PKD classes "Manufacture of domestic appliances" and "Repair and maintenance of personal and household goods" belonging to these divisions.

Since the transformation from a socialist centrally planned economy to a market economy, Poland had experienced an uninterrupted period of positive economic growth till the pandemic. Even during the great financial crisis of 2008–2010, growth in Poland remained high. However, a marked decline in real GDP growth of Poland occurred in the first year of the pandemic (2020), followed by a sharp recovery in the next two years. Figure 2 presents Poland's real GDP growth. GDP per capita in PPP terms, experienced an exponential trend (marked by a dotted line) from the beginning of the 1990s,

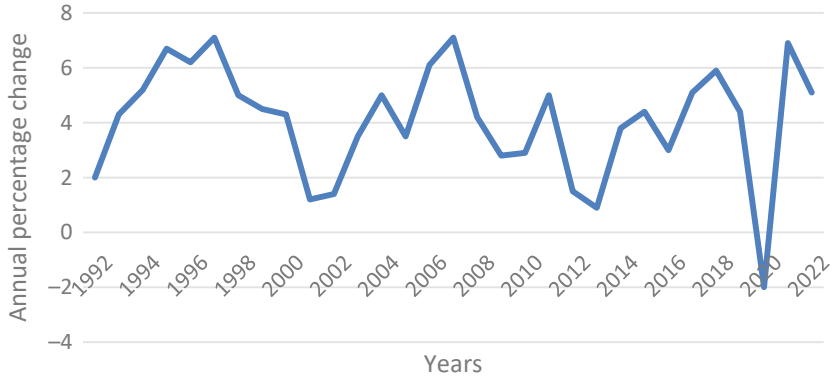

Figure 2. Real GDP growth of Poland

Source: (https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/POL?zoom=POL&highlight=POL).

according to Figure 3. In just the first year of the pandemic, the economy deviated markedly from it. Over the next two years, the economy converged to or even surpassed this trend.

The above can be treated as evidence that the Polish economy quickly returned to its pre-COVID trajectory and substantial economic growth. It might implicitly prove that the fiscal programs implemented to support enterprises during the pandemic were effective. Apart from the general programs, the

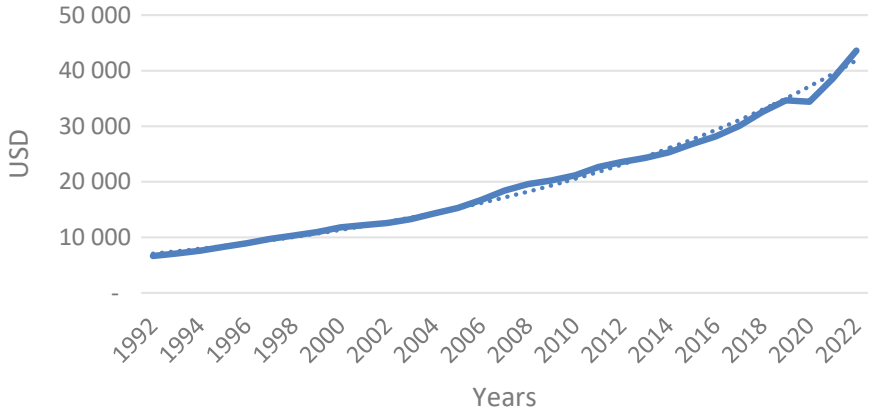

Figure 3. GDP per capita (current prices, PPP) of Poland

Source: (https://www.imf.org/external/datamapper/PPPGDP@WEO/POL?zoom=POL&highlight=POL).

specific programs were suited to the specific needs of various economic sectors, represented in this research by the PKD divisions. Of course, one could argue that this state aid was too generous, and that there were certainly enterprises which should not have received this assistance but did. However, in crisis prevention, overreaction is preferable being overcautious. Moreover, given the time pressure, doing too much with these programs was better than doing too little.

3.2. Robustness checks

To assess the statistical robustness of the above results, we use the non-parametric Mann Whitney (1947) test, in lieu of the Wilcoxon. The Mann-Whitney *U* test operates under slightly different assumptions than the Wilcoxon test. While the Wilcoxon test assumes independent differences between paired observations and symmetrical distribution of those differences between groups, the Mann-Whitney *U* test assumes independent samples and similar shapes in the underlying distributions of the two groups. Because the two observations come from the same company, and from two consecutive years, they are certainly not independent. Hence, the Wilcoxon test better fits this situation than the Mann-Whitney *U* test. However, the latter test serves as an appropriate robustness check because it tests the same null hypothesis under different assumptions (independent samples and similar distribution shapes rather than paired differences). Thus, if both tests yield similar results, it strengthens confidence in the findings' statistical validity, regardless of the underlying data structure.

Table 2. Robustness checks

Checks	RS	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
check1	48%	81%	79%	59%	72%	69%	75%	85%	83%	61%	95%
check2	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: own calculations.

Nevertheless, we use the second test as a robustness check. As the first check, the percentage of PKD divisions which gave the same results for both tests can be verified. The first row of Table 2 presents the results. In the second row of the table, the 2nd check is presented, which verifies the consistency of extreme results for both tests, i.e. if one test generates output 1 or 0 and the other generates output 1 or 0 too, or if one test generates output –1, 0 and the other generates output from the same range. The results of the second check and the initial output table are consistent. However, there are notable discrepancies in intermediate cases, which are particularly evident in Revenues from Sales (RS). This lower concordance rate for RS suggests that the choice of test methodology may be particularly important when analysing revenue changes. These discrepancies warrant deeper analysis for several reasons. Firstly, they may indicate cases where the underlying assumptions of each test become crucial: the Wilcoxon test's assumption of symmetrical differences versus the Mann-Whitney's assumption of similar distribution shapes. Secondly, divisions showing different results between tests might represent cases where the financial impact of COVID-19 was more ambiguous or complex. Thirdly, the varying concordance rates across different financial ratios suggest that some metrics may be more sensitive to the choice of statistical methodology than others. These variations ultimately strengthen the study's reliability by demonstrating the robustness of the main findings across different statistical approaches, while also highlighting areas where results should be interpreted with additional caution.

The above findings complement the existing literature by offering a more granular understanding of the pandemic's heterogeneous effects across 75 PKD divisions, in contrast to the global or macroeconomic focus of studies like McKibbin and Roshen (2023) and Alon et al. (2023). The current study identifies the most severely affected sectors and those that experienced growth, aligning with the findings of Kwiatkowski and Szymańska (2022) on employment reallocation shocks in Poland. The deterioration of financial ratios in most sectors is consistent with the supply chain disruptions highlighted by Kazancoglu et al. (2023). The research also emphasises the role of government liquidity injections in stabilising financial conditions, providing a detailed account of the specific measures implemented under the Anti-Crisis Shields, complementing the conclusions of McCann et al. (2023) and Guedegbe (2022) on the importance of policy responses.

The authors admit that it is difficult to distinguish between the government interventions and the possible moral hazards that these actions may lead to. Certainly, not every crisis should force government intervention to prevent moral hazards. However, in the case of the COVID-19 pandemic, which caused public isolation, world trade disruption, and medical threats, such government action was justified. We note that the Polish government was not alone in intervening, and did not permit the shutdown to further deteriorate the living standard of its population. In this regard, governments throughout the world followed the advice of John Maynard Keynes, and also of Ben S. Bernanke in the wake of the 2008–2009 global financial crisis. In future economic crises, whether due to health, natural disasters, or finance, policy makers should consider and balance the consequences of coming to the rescue when it is not justifiable.

Conclusions

COVID-19 had an enormous impact on the economies of numerous countries. This paper uses financial data from more than 150,000 Polish enterprises and explores varied effects brought by COVID-19 across multiple sectors.

The Polish government implemented a portfolio of measures under its Anti-Crisis Shields programs, providing liquidity and supporting businesses during the COVID-19 pandemic. These measures included subsidies for salaries and social security contributions, loan guarantees, direct loans, deferral of tax payments, tax exemptions, moratorium on loan repayments, and specialised additional aid for different categories. Estimates suggest that these measures amounted to more than PLN 200 bn in 2020. Clearly, such generous support by the Polish government poses a moral hazard, inducing future generations to anticipate future handouts, whether justifiable or not. This study reports that government subsidies were allocated to particular distressed sectors, thereby averting their collapse and a potential downturn in the entire Polish economy. It is true, though, that parts of these subsidies were utilised outside of targeted sectors, causing inefficiencies and unintended consequences. However, in the authors' opinions, the magnitude of the global crisis and its exponential spread justify such large-scale governmental interventions.

From the variable values for all financial ratios across all PKD divisions investigated here, it can be observed that Days Receivable Outstanding, Days Inventory Outstanding, and overall Cash Conversion Cycle deteriorated in most divisions because of delayed payment of trade receivables from enterprises. Despite these disruptions, the government's liquidity injections helped sta-

bilize financial conditions, by showing that the overall liquidity, measured by Quick Ratio and Cash Ratio, apparently increased for almost all PKD divisions.

The COVID-19 pandemic had a substantial impact on the Polish economy, with varying effects across different sectors. The government's targeted support programs, such as the substantial aid for Polskie Linie Lotnicze LOT S.A., the tourist voucher initiative, and the "Culture Online" program, were crucial in stabilizing affected industries. Sectors like retail and hospitality faced severe downturns, yet technology and veterinary services experienced growth due to increased demand for remote work solutions and pet care. The effectiveness of government interventions highlights the importance of tailored and robust policies in mitigating economic crises and fostering a resilient recovery. Continued support and strategic investments remain vital for sustained economic stability and growth.

The COVID-19 pandemic interrupted Poland's long period of economic growth, causing a significant GDP drop in 2020. However, the economy rebounded quickly, surpassing its pre-pandemic growth levels by 2022. This rapid recovery proved the efficacy of the government's fiscal support programs, indicating that these were crucial in stabilising the economy, while also stressing that during tough economic times, it is advisable to offer more government support than too little.

The robustness checks using the Mann-Whitney *U* test confirmed the reliability of the results obtained with the Wilcoxon test. The findings are validated by the consistent outcomes across both tests, which reinforces the statistical reliability of the conclusions regarding the economic impacts of COVID-19 on Polish enterprises. This approach ensures that the observed effects are credible, providing a solid foundation for the analysis presented in the paper.

Moreover, it may be of interest to compare differences among sectors, and further aggregation of industries may prove useful. An additional possibility involves adding more years as we move from 2022 and 2023 to 2024. Furthermore, one may introduce macroeconomic factors such as Gross Domestic Product, Industrial production, number of employees in each sector, etc., into the analysis to infer the different elasticities in response to government policies and sectors' characteristics, such as ease of reallocating resources in times of blockage. This will require the implementation of panel-data econometrics.

Future research might also benefit from exploring why certain financial metrics show greater sensitivity to test selection and whether this reflects underlying economic phenomena or statistical artifacts. Future research may involve comparing the measures used by the Polish Government with other Central and Eastern European countries. We live in a world of uncertainty, as the conflict between Russia and Ukraine has proven.

Appendix 1

Definitions of financial ratios

RS – Revenues from Sales
d% *RS* – percentage change of Revenues from Sales between 2020 and 2019 years.

List of financial ratios:

(1) profitability ratios:

- *R*1: Operating Profit Margin = Operating profit / Revenues from Sales,
- *R*2: Return on Assets = Net income / Total assets,

(2) liquidity ratios:

- *R*3: Quick Ratio = (Current assets – Inventories – Biological assets – Intangible assets) / Short-term liabilities,
- *R*4: Cash Ratio = Cash and cash equivalents / Current liabilities,

(3) working capital ratios:

- *R*5: Cash Conversion Cycle = (Days Receivables Outstanding + Days Inventory Outstanding) – Days Inventory Outstanding,
- *R*6: Days Receivables Outstanding = Average receivables / Sales revenue × 365 [days],
- *R*7: Days Inventory Outstanding = Average inventory / Operating expenses × 365 [days],
- *R*8: Days Payable Outstanding = Average short-term trade liabilities / Operating expenses × 365 [days],

(4) financial leverage ratios:

- *R*9: Debt Ratio = Liabilities / Total assets,
- *R*10: Interest Coverage Ratio = (Operating profit + Depreciation) / Financial costs.

Appendix 2

List of PKD 2007 codes (economic sectors) and related divisions

PKD	Full name
01	Crop and animal production, hunting, including service activities
02	Forestry and logging
03	Fishing and aquaculture
08	Other mining and quarrying
10	Manufacture of food products
11	Manufacture of beverages
13	Manufacture of textiles
14	Manufacture of wearing apparel
15	Manufacture of leather and related products
16	Manufacture of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
17	Manufacture of paper and paper products
18	Printing and reproduction of recorded media
19	Manufacture and processing of coke and refined petroleum products
20	Manufacture of chemicals and chemical products
21	Manufacture of basic pharmaceutical substances and medicines and other pharmaceutical products
22	Manufacture of rubber and plastic products
23	Manufacture of other non-metallic mineral products
24	Manufacture of metals
25	Manufacture of fabricated metal products, except machinery and equipment
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment not elsewhere classified
29	Manufacture of motor vehicles, trailers and semi-trailers excluding motorcycles
30	Manufacture of other transport equipment
31	Manufacture of furniture
32	Other manufacturing
33	Repair, maintenance and installation of machinery and equipment
35	Electricity, gas, steam, hot water and air conditioning manufacturing and supply
36	Water collection, treatment and supply
37	Sewage disposal and treatment

38 Waste collection, processing and neutralizing activities; materials recovery
39 Remediation activities and other waste management services
41 Construction of buildings
42 Works related to construction of civil engineering
43 Specialised construction activities
45 Wholesale and retail trade of motor vehicles; repair of motor vehicles
46 Wholesale trade, excluding motor vehicles
47 Retail trade, except retail trade of motor vehicles
49 Land transport and transport via pipelines
50 Water transport
51 Air transport
52 Warehousing and support activities for transportation
55 Accommodation
56 Food and beverage service activities
58 Publishing activities
59 Motion picture, video and television program production, sound recording and music publishing activities
60 Public and license programmers broadcasting
61 Telecommunications
62 Computer programming, consultancy and related activities
63 Information service activities
68 Real estate activities
69 Legal, accounting, bookkeeping and auditing activities; tax consultancy
70 Activities of head offices; management consultancy activities
71 Architectural and engineering activities; technical testing and analysis
72 Scientific research and development
73 Advertising and market research
74 Other professional, scientific and technical activities
75 Veterinary activities
77 Rental and leasing activities
78 Employment activities
79 Tour operator, middlemen, agents and other reservation service and related activities
80 Security and investigation activities
81 Services to buildings and landscape activities
82 Office administrative service activities and other business support activities
84 Public administration and defence; compulsory social security
85 Education
86 Human health activities
87 Residential care activities
88 Social work activities without accommodation
90 Creative, arts and entertainment activities

91 Libraries, archives, museums and other cultural activities
93 Sports activities and amusement and recreation activities
94 Activities of membership organisations
95 Repair and maintenance of computers and personal and household goods
96 Other personal service activities

Appendix 3

The output table, all sectors

PKD	d% RS	RS	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
79	–70	–1	–1	–1	–1	0	–1	–1	0	1	–1	–1
51	–55	–1	0	0	0	1	–1	–1	0	0	0	0
90	–46	–1	–1	–1	0	0	–1	–1	0	1	–1	–1
55	–39	–1	–1	–1	–1	0	–1	–1	0	1	–1	–1
56	–24	–1	–1	–1	–1	–1	–1	–1	–1	1	–1	0
91	–18	–1	–1	–1	–1	0	–1	–1	0	0	–1	0
93	–16	–1	–1	–1	0	1	–1	–1	0	1	–1	0
15	–14	–1	0	0	1	1	–1	–1	–1	0	0	0
60	–13	0	0	0	0	1	0	0	0	0	0	0
94	–13	–1	0	0	0	1	–1	–1	0	0	0	0
29	–12	–1	0	–1	1	1	–1	–1	–1	1	0	0
08	–11	–1	–1	–1	–1	1	–1	–1	0	0	–1	0
24	–9	–1	1	1	1	1	–1	–1	–1	1	0	1
45	–8	–1	0	–1	1	1	–1	–1	–1	0	0	0
02	–8	–1	0	–1	0	0	–1	–1	0	1	–1	0
96	–7	–1	–1	–1	0	1	–1	–1	0	0	–1	0
68	–6	1	1	–1	1	1	–1	–1	0	0	–1	0
50	–6	0	0	0	0	1	0	0	0	0	0	0
78	–6	–1	–1	–1	0	1	–1	–1	0	1	–1	0
73	–5	–1	–1	–1	0	1	–1	–1	0	1	0	0
14	–5	–1	0	0	1	1	–1	–1	–1	0	0	0

PKD	d% RS	RS	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
58	–4	–1	0	0	1	1	–1	–1	0	0	0	0
28	–4	–1	0	0	1	1	–1	–1	–1	1	0	0
70	–4	0	0	–1	1	1	–1	–1	0	0	0	0
69	–3	1	1	–1	0	1	–1	–1	0	0	0	0
25	–2	–1	0	–1	1	1	–1	–1	–1	1	–1	0
85	–2	–1	0	–1	0	1	–1	–1	0	1	–1	0
18	–2	–1	0	–1	1	1	–1	–1	0	0	0	0
23	–1	0	0	–1	1	1	–1	–1	–1	0	0	0
31	–1	1	1	0	1	1	–1	–1	–1	0	–1	0
43	–1	0	–1	–1	1	1	–1	–1	0	0	–1	0
30	–1	0	0	0	0	1	–1	–1	0	0	0	0
77	–1	–1	0	–1	1	1	–1	–1	0	1	0	0
19	–1	0	0	0	0	1	0	–1	–1	0	0	1
17	–1	0	1	1	1	1	–1	–1	–1	0	0	1
82	–1	–1	–1	–1	0	1	–1	–1	0	1	0	0
49	0	0	1	1	1	1	–1	–1	0	1	1	1
13	0	0	1	1	1	1	–1	–1	–1	1	0	1
52	1	1	1	0	1	1	–1	–1	0	1	1	0
22	1	1	1	1	1	1	–1	–1	–1	0	1	1
11	2	0	0	0	0	0	–1	–1	–1	0	0	0
71	2	0	–1	–1	1	1	–1	–1	0	0	–1	0
46	2	0	1	1	1	1	–1	–1	–1	0	1	0
20	3	1	1	1	1	1	0	0	–1	0	1	1
47	3	0	1	1	1	1	–1	–1	–1	0	0	0
80	3	1	0	0	1	1	0	0	0	0	1	1
39	3	0	1	0	0	1	0	0	0	0	0	0
36	3	1	–1	–1	0	1	0	0	0	0	0	0
01	3	1	1	1	1	1	–1	–1	0	0	1	1
88	4	1	0	0	1	1	–1	–1	0	0	0	0
16	4	0	0	0	1	1	–1	–1	0	0	0	0
26	4	1	1	1	1	1	–1	0	0	0	0	1
37	4	1	0	0	0	1	0	0	0	0	0	1

PKD	d% RS	RS	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
87	4	1	0	0	1	1	0	–1	0	0	1	0
32	5	0	1	0	0	1	–1	–1	–1	0	–1	0
74	5	0	0	–1	0	1	–1	–1	0	0	0	0
61	5	1	0	0	1	1	–1	–1	0	0	1	0
10	5	0	1	1	1	1	–1	0	–1	0	0	1
86	6	1	1	–1	1	1	–1	–1	0	1	0	0
72	6	1	0	0	0	0	–1	–1	0	0	–1	0
33	6	–1	–1	–1	0	1	–1	–1	0	1	–1	0
42	7	–1	–1	–1	0	1	–1	–1	0	1	–1	0
81	7	1	0	–1	1	1	–1	–1	0	0	0	0
41	7	1	1	–1	1	1	–1	–1	0	0	–1	0
35	8	1	1	1	1	1	0	0	0	0	0	0
21	8	1	1	1	0	1	0	0	–1	0	0	0
03	8	1	0	0	1	1	0	0	0	0	1	0
63	8	1	1	0	1	1	–1	–1	0	0	0	0
59	10	–1	0	–1	0	0	–1	–1	0	1	–1	0
84	10	0	0	0	1	0	0	–1	0	1	0	0
38	17	1	1	1	1	1	–1	–1	0	0	1	1
75	19	1	0	0	1	1	–1	–1	0	0	0	0
95	20	0	0	0	0	0	–1	–1	0	0	0	0
27	21	0	1	0	0	1	–1	0	–1	1	0	1
62	23	1	1	0	1	1	–1	–1	0	0	1	0

Source: own calculations.

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Inflation expectations proprieties during the war: The case of Ukraine

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Abstract

This study compares consumer and professional inflation expectations in Ukraine before and during the Russian invasion of Ukraine. We apply entropy-based measures to tackle co-movements of expectations and macro variables (inflation, food inflation, exchange rate and production) and dynamic time warping to assess their forward and backward orientation. The pre-war sample spans from May 2019 to February 2022, and the war sample from March 2022 to December 2024. We expected to find differences between pre-war and wartime samples, as war constitutes a political shock with severe economic consequences. The study confirms the change of expectations: more substantial mutual information with past inflation in most cases, better alignment between professionals and consumers, and a change in the distances between expectations and past or future inflation. This is the first empirical study discussing Ukrainian

Keywords

- inflation expectations
- mutual information
- dynamic time warping
- war

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economic agents' expectations during the full-scale invasion. Its novel aspect also concerns the method applied—standard procedures cannot be used for this sample length.

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Introduction

We seek to investigate inflation expectations in Ukraine because they are a key variable from the point of view of monetary policy (Woodford, 2003). However, they have not yet been analysed in the context of war, and in Ukraine, a country currently under attack, these expectations were not widely studied even in the pre-war context. In this study, we fill this gap in the literature by providing the first empirical evidence on consumer and professional expectations during the invasion, which are assessed with an alternative methodology differing from standard studies. The wartime subsample is distinctive not only because of its length (34 observations) but also due to the structural breaks and new patterns of expectation formation that can be expected in a turbulent environment. These patterns affect the distributions and properties of the time series. Thus, we have chosen to employ alternative methods rather than standard regression-based approaches for this study.

The National Bank of Ukraine (NBU) has implemented inflation targeting since 2017. This strategy is based on stabilising expectations through policy actions and has proved to be a successful policy framework in many economies. However, Ukraine is a developing economy with a shorter history of inflation targeting and interrupted disinflation process even before the surge in global inflation. During Ukraine's early years of inflation targeting, the level of inflation deviated from the upper or lower band of fluctuations, consistently raising questions about the NBU policy's impact on price stability (Gertchev, 2021).

Russia's invasion changed the structure of Ukraine's economy. The National Bank of Ukraine's priorities shifted from price stability to macro-stabilisation and to financing war expenditures (Danylyshyn & Bohdan, 2022). The inflation targeting framework was modified by pegging the hryvnia rate to the US dollar, introducing restrictions in the FX market, closer cooperation with the state administration, and the NBU financing war expenses. This change

in the economy and in monetary policy affected the expectations of economic agents. Moreover, even though the invasion occurred during an inflation surge, it triggered inflation globally, as presented by Maurya et al. (2023). The invasion affected infrastructural and production facilities, the labour market, supply channels, availability, and prices of basic consumption goods. It also triggered a psychological shock for Ukrainian citizens. Thus, there are numerous reasons why one might expect a change in the expectations formed by Ukraine's economic agents.

This study's results can provide information on the proprieties of expectations during the invasion compared to the pre-invasion period. Recognising a new pattern has practical implications for the National Bank of Ukraine. It also allows the NBU to assess the efficiency of its policy and communication.

In this paper, we use monthly aggregated data on consumer expectations derived from the NBU dataset and Consensus Forecast data for professionals. We apply entropy measures (mutual information and mutual conditional information) and dynamic time warping (DTW) to identify the co-dependencies between professional and consumer expectations and inflation, food inflation, exchange rates and production, and the degree of expectations' forward orientation during the Russian invasion of Ukraine. The study covers Ukraine from May 2019 to December 2024, and the research period is divided into a 'pre-war' and 'during the war' subsample.

Compared to standard methodology (based on regressions), the approach here has the advantage of not requiring assumptions about distributions, lags and estimators, as presented by Rutkowska and Szyszko (2022). They could also be applied to shorter samples, such as ours. DTW is often used to overcome distortions by aligning and classifying time series (El Amouri et al., 2023). It was applied to discuss business cycles by Raihan (2017), and Franses and Wiemann (2020). Entropy measures were used to identify information flow in a financial context by Lahmiri and Bekiros (2020), and Będowska-Sójka et al. (2021). Entropy-based measures are used also to analyse uncertainty and information flow. For example, Shoja and Soofi (2017) and Gülşen and Kara (2019) explore uncertainty and disagreement among economic forecasters using entropy measures, and Grimme et al. (2014) to study inflation uncertainty. Camacho et al. (2021) apply transfer entropy to develop a non-parametric Granger causality test for longitudinal data, and Behrendt and Schmidt (2021) utilise transfer entropy and mutual information to investigate the nonlinear relationships between stock prices and trading volume. Applying entropy measures to tackle expectation proprieties was presented by Rutkowska et al. (2024).

The remainder of this paper is organised as follows: Section 1 briefly reviews existing literature in the field, and Section 2 presents the sample and data used; Section 3 describes the study's methods and Section 4 presents and discusses our results and analysis. The paper concludes with our findings.

1. Literature review

The existing literature does not directly discuss the evolution of expectations in Ukraine during the war. However, some studies suggest that war affects global and local inflation. Dräger et al. (2022) consider the war to be a political shock which, like natural disasters, has significant and long-term effects on private forecasts for inflation. Liadze et al. (2023) estimate that the war increased global inflation by 2 p.p. in 2022 and 1 p.p. in 2023. The idea of war being an extra trigger for global inflation is also discussed by Maurya et al. (2023). Moreover, times of heightened general uncertainty are mirrored by increased uncertainty about future inflation (Londono et al., 2023). Although this paper does not tackle the uncertainty directly, we can assume that war-related uncertainty affects expectation formation patterns.

Despite the importance of recognising expectations patterns after the day of the invasion, Ukrainian consumers and professionals have not yet been empirically tested for changes in their expectations. However, some studies for European economies confirm the immediate change in expectations due to the invasion: one for Germany (Afunts et al., 2023) and one for Italy (Ropele & Tagliabracci, 2024). They analyse the expectations survey results among individuals and companies. They also replicate natural experiment settings, as both started before the day of the invasion and continued afterwards. The results report an immediate response to expectations due to the war eruption.

Additionally, Dräger et al. (2022) surveyed German economic experts just after the day of the invasion and confirmed the immediate response to their forecasts of inflation: they increased by 0.75 p.p. for 2022. The descriptive question regarding the possible reasons for this increase proves that German experts attribute it directly to war-related factors. Interestingly, when the results were compared to the study of a representative sample of households, the authors found consumers' reactions were both lagged and much lower.

Past studies on Ukraine's expectations are rare and not linked directly to political shock. Studies discussing expectation forward- and backward-lookingness hardly exist. As indicated by Lukianenko et al. (2022), when forecasting prices, professionals tend to base on past forecasts, especially if the economic situation in the country is mostly unstable and there is significant uncertainty about inflation in subsequent periods. However, no econometric analysis supports this assertion. Zholud et al. (2019) conclude that private forecasts are non-rational, identifying some forward-looking components in expectations, which are higher for professionals. Gertchev (2021) notes that consumer and professional inflation expectations before the pandemic diverged from actual inflation and the NBU forecasts, concluding that households deliberately ignored or disagreed with the central bank's announcements. Again, this conclusion is based on data observations not supported by a statistical study.

Ukrainians operate in a higher-inflation environment, which transforms into more attention being paid to inflation than by private entities in advanced economies with a longer history of successful inflation targeting (Coibion et al., 2020). The Ukrainian economy operated in a more turbulent environment even before the war. Past studies on expectations conducted for Ukraine and published in English are observational studies that do not cover the most recent evolution of expectations. Therefore, the novel aspect of this work lies in its empirical analysis of recent dependencies between expectations of two groups of economic agents and macro variables.

Assuming that the rational expectation hypothesis does not describe the actual behaviour of expectations when searching for theoretical premises regarding the change of expectations due to the invasion, we can refer to the fact that economic agents face the costs of collecting, absorbing and processing information. As presented by Mankiw and Reis (2002) and Reis (2006), they remain inattentive and do not update expectations daily. The outbreak of war is an event worth noting and, contrary to how standard economic news is disseminated, news about military aggression spreads quickly and easily among society. Thus, we assume inflation expectations during the invasion behaved differently to the pre-invasion period. The differences appear in orientation towards the future, coordination of information content, and alignment.

In addition to the theoretical premises that allow us to assume that Ukrainian consumers and professionals changed their expectations, there are several other channels through which the war can affect expectation formation. These are linked to the economic shock initiated by the invasion, psychological and behavioural factors, and policy measures applied. These channels interlink. Determining which matters most is challenging because individual respondents can simultaneously associate the war with multiple aspects directly affecting the economy and inflation (Afunts et al., 2023). Moreover, professionals might react to different factors than consumers.

Psychological factors relate to the intense psychological pressure stemming from the invasion. This pressure affected the perception of the current and future economic situation. The panic was well grounded in the current political and economic situation, also affecting expectation formation. The most immediate consequences of Russia's invasion were deaths, the physical destruction of infrastructure and production facilities, and the occupation of some territories (NBU, 2022a). The war disrupted supply chains, reduced the supply of some goods, raised companies' operating costs and increased business risk. Seiler (2022) attributes the increase in inflation expectations in Ukraine directly to supply-side distribution and the surge in energy costs. Economic agents, especially households, become more pessimistic in such circumstances and less able to process incoming information. As presented by Guirola and Kataryniuk (2022), consumers whose medium-term inflation forecasts went up during the Russian invasion of Ukraine were, on average,

those who became most pessimistic about the economic outlook. The rise in pessimism as a mechanism that transforms into higher expectations was also confirmed for German consumers (Afunts et al., 2023). A similar situation could arise in Ukraine: a pessimistic economic outlook and elevated expectations.

Due to the direct consequences of the invasion, economic agents operated under a psychological shock, which the National Bank of Ukraine also noted and incorporated in its decisions: the NBU abandoned the standard policy instrument, interest rates, as their transmission was deemed ineffective (NBU, 2022a). Pegging the exchange rate and introducing FX restrictions were policies to support macro stabilization and anchor economic agents' expectations. Still, the monetary policy framework change is one of the most important channels affecting expectation formation after the outbreak of the war. The nominal anchor was shifted from the inflation target to the exchange rate.

The next aspect that could lead to a change of expectations formation during the war was the economic agents' lifetime inflation experience. Past inflation experience matters when consumers make decisions on the direction of future price changes, but is less relevant when considering the level (Conrad et al., 2022). Ukraine's economic agents experienced many economic crises and inflation episodes, which could fuel the increase in inflation expectations. It is also linked to the rise in global inflation just after the breakout of war: one of the possible channels through which the invasion could impact expectations negatively in Ukraine is the elevated global and domestic inflation at the time of the invasion. As inflation remained high and rose, the war was an extra boost for economic agents to raise their expectations in unfavourable conditions. Ukrainians also reacted to higher energy prices, food prices (the most important components of their consumption basket), and the unavailability of some goods and services. As suggested by Galati et al. (2022), inflation outcomes speak louder than central bank words (declaration) when it comes to households' inflation expectations. The higher risk of unanchored expectations under more extended periods of elevated inflation is more profound for consumers and companies but also occurs for specialists (Coibion et al., 2020; Galati et al., 2022). This effect is observed even in advanced economies (Moessner & Takáts, 2020). More focus on current inflation is also expected for Ukraine's economic agents (Coibion & Gorodnichenko, 2015; Coibion et al., 2020).

Inflation expectations could also be fuelled by the massive financing of budget needs introduced immediately after the invasion. In 2022, the NBU financed one-third of the state's borrowing needs. Even though the NBU announced that it would only finance critical government and social expenditures while maintaining maximum transparency of these transactions (NBU, 2022b), economic agents, especially professionals, might expect an inflationary effect from such an action.

Past studies regarding expectation evolution allow us to assume that:

H1: The characteristics of economic agents' expectations in Ukraine are different during the war as compared to pre-invasion.
H2: During the war, economic agents are more oriented toward the future when forecasting inflation.
H3: As war and war news spread widely and fast, the coordination between professionals and consumers is higher during the invasion.

2. Sample and data

2.1. Dataset

The study focuses on short-term expectations (12M), as long- term surveys are unavailable for consumers. The sample was divided into two subsamples: 'the pre-war' (May 2019–February 2022) and 'during the war' (March 2022–December 2024). We arbitrarily chose the sample to keep the same number of observations in both subsamples. The 'during the war' sample starts in March, as the invasion occurred after the surveys were conducted. As presented in Section 2, studies regarding expectation formation just after the invasion for other economies suggest a change in the formation pattern. Moreover, a preliminary study also identified structural breaks in the expectations time series for Ukraine. In this study, we use the following data sets:

– for consumers: quantified results of expectation surveys provided by the NBU,
– for professionals: Consensus Forecasts of Consensus Economics,
– inflation rate, including food inflation: the main statistical office's data collection,
– the industrial production index, exchange rates of Ukrainian hryvnia to the euro (EUR/UAH), and US dollar (USD/UAH): NBU statistical releases.

For consumers, we use the National Bank of Ukraine dataset. The NBU declares that the methodology used for conducting these surveys aligns with international standards (NBU, 2025). However, a more detailed description can only be derived from the work of Coibion and Gorodnichenko (2015). Consumers select from a set of inflation brackets running at five percent increments. They respond to the survey question: 'Inflation over the next twelve months will be':

– less than zero (prices will fall),
– between 0 and 5%,

– between 5 and 10%, etc.,
– more than 30% (extended to 50% in 2015),
– it is difficult to answer.

The last bracket from the set of responses, allowing responders to choose the highest inflation, changes over time, reflecting economic conditions. The proxy of expectation is the arithmetically weighted average value of responses. 'It's difficult to answer' answers are excluded from quantification.

Consensus Economics forecasts of professionals are fixed-event forecasts. Professionals present their expectations for the end of the current and the following year. We transform them into fixed-horizon (12M) forecasts, as suggested by Dovern et al. (2012), using weighted averages of fixed-event forecasts.

We consider standard macro variables, which are important drivers of expectations, in the analysis of codependencies run with mutual information. These are inflation, food inflation, hryvnia exchange rates vis-a-vis the euro and US dollar and industrial production index (IPI). This set of variables is a standard when expectations drivers are discussed (e.g., see Łyziak, 2014; Łyziak & Mackiewicz-Łyziak, 2014; Szyszko et al., 2020). As the NBU pegged the hryvnia exchange rate for the first 18 months of the invasion and then applied market interventions to stabilise it, making the exchange rate a nominal anchor, we perceive it as an essential inflation driver in the case of Ukrainian economic agents' expectations. The industrial production index represents Ukraine's real economic evolution. During the war, changes in economic growth or even production possibilities were easily observed, and this is why we decided to discuss them in the context of common information.

Additionally, food inflation was used as one of the coordinating factors. It is more straightforward for consumers to observe, as its weight in the consumer basket accounts for 46%.[4] This is of great significance for the perceived inflation, which constitutes the benchmark for expectation formation. Abildgren and Kuchler (2021) confirm that consumers may have another price concept in mind (food prices) rather than consumer prices in general when interviewed about the level of inflation. The reaction of food inflation to geopolitical risk was confirmed by Sohag et al. (2023).

We report the dependencies between expectations and macro variables, assuming that economic agents are informed about inflation lagged by 1M and 2M when forecasting inflation. This is the standard assumption, as inflation estimates for a previous month are published at the end of the subsequent month. The survey preceded the publication date. Moreover, due to their low level of financial and economic literacy and the slow spread of economic news, consumers need more time to process news on inflation. We

[4] The latest estimates by the State Statistics Service of Ukraine provided for 2021. The basket structure during war time was not updated.

assume that a 1M lag could be enough for professionals but not necessarily for consumers. A longer lag is a standard assumption when expectation proprieties are tested (see Gerberding, 2001; Łyziak & Mackiewicz-Łyziak, 2014). We applied a 2M lag for the industrial production index, as the publication lag is more substantial than for inflation. Finally, only 1M lag was used for the exchange rate, since this variable is easily observed on a daily basis.

To analyse forward and backward orientation, we compared the distances between expectations and inflation or food inflation because the inclusion of other variables (industrial production index and exchange rate) would not be economically meaningful in this context.

The dataset provided above was used to identify (1) the dependencies between variables with the entropy measures and (2) the forward and backward orientation of consumer and professional expectations with the DTW algorithm.

2.2. Data description and properties

Figure 1 presents inflation, consumer expectations and professional expectations in Ukraine. Before the full-scale war, disinflation was still in progress, with the latest inflation target set at 5%, even though it temporarily reached single-digit levels and dropped below the inflation target during the research period of this study.

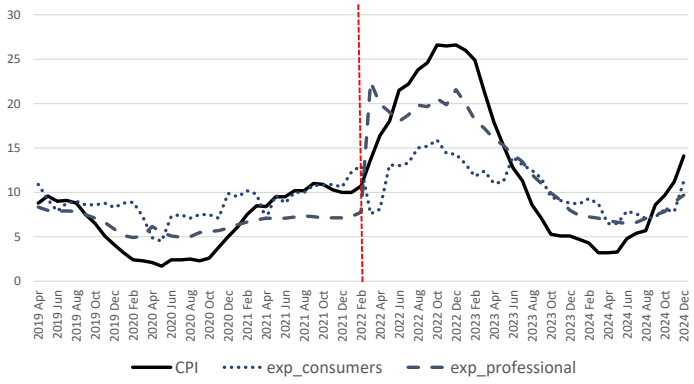

Figure 1. Inflation and expectations in Ukraine

Source: based on the datasets described in this section.

During the war, professional expectations in Ukraine were closer to actual inflation than consumers'. The reaction of Ukrainian experts to the invasion, expressed in the great increase in expectations, was immediate and simi-

lar to the response of German experts, as presented by Dräger et al. (2022). However, they overshoot inflation for only about one quarter.

Interestingly, consumers' reactions were quite the opposite. Their expectations dropped to one-digit levels in March and April 2022. The NBU assumes that they might be affected by the change of survey method from face-to-face to a telephone interview. A similar change was applied during the lockdowns, resulting in an expectation drop (NBU, 2022a). These results could also have been affected by the change in the localisation of survey participants. According to Coibion and Gorodnichenko (2015), substantial cross-regional differences in survey results occurred. Responders from East and South Ukraine expressed higher inflation expectations. As these territories were occupied, the sample could be moved to non-occupied regions, expressing lower expectations. During the invasion, particularly at the beginning, measuring and forecasting inflation was significantly hindered due to the change in the available basket of goods and services. Therefore, households that use their own basket to assess and forecast inflation might have had different forecasts than those in the standard situation. Moreover, the households might have reacted to the general stabilisation programme started by the NBU and supported by the government's actions. Fixing the exchange rate could be considered an effective stabilisation mechanism, and the information already announced regarding the government suspending rises in heat and gas prices or decreasing indirect taxes might have fostered a temporary lowering of expectations. The study by Savolchuk and Yukhymenko (2023) confirms the increase in perceived central bank credibility at the beginning of full-scale invasion as the response to applied stabilisation measures. Even though the study was conducted for companies, they are more commonly represented by individuals, not professionals. It is worth noting that the NBU did not pay great attention to the decrease in consumer expectations. It expressed fears regarding the increase in expectations driven mostly by supply-side factors and their anchoring (NBU, 2022a).

Since mid-2023, the economic situation in Ukraine has been more stable, including declining inflation, and an economic rebound. The NBU reacted accordingly, making the monetary policy more accommodative. The first interest rate cut occurred in July 2023 and was followed by several cuts, up to June 2024. The pegged exchange rate was replaced with managed floating, which provided greater scope for NBU intervention in the FX market. Since June 2023, consumers and professionals have overestimated inflation, and the time series become more aligned.

Table 1 presents descriptive statistics for our sample. As the time series are non-stationary, we do not use them to draw conclusions about differences but to provide the preliminary characteristics of the sample. The mean level of expectations for consumers and professionals after the invasion was higher. On average, specialists increased their forecasts more than consum-

Table 1. Descriptive statistics for data

	Inflation	Food inf	Exp Con	Exp Prof	EUR/UAH	EUR/UAH	IPI
	Before the war						
Mean	6.62	7.55	8.85	6.55	30.79	26.84	98.51
Median	7.50	8.50	8.80	6.98	30.97	27.07	99.80
Standard deviation	3.33	4.22	1.80	1.00	2.50	1.49	3.78
Kurtosis	–1.66	–1.34	0.68	–1.28	–1.03	–0.52	–1.49
Skewness	–0.22	0.00	–0.15	–0.33	–0.45	–0.54	–0.34
Minimum	1.70	1.30	4.50	4.92	26.10	23.85	91.90
Maximum	11.00	14.30	13.00	7.99	34.20	29.60	103.30
	During the war						
Mean	13.49	15.72	10.73	13.34	39.77	37.17	89.69
Median	12.05	13.80	11.10	12.72	39.91	36.57	97.50
Standard deviation	8.32	12.49	2.85	5.62	3.82	3.52	19.54
Kurtosis	–1.41	–1.46	–1.35	–1.68	0.21	0.99	–1.68
Skewness	0.32	0.21	0.13	0.15	–0.68	–1.03	–0.25
Minimum	3.20	–0.50	6.50	6.49	30.78	29.25	61.00
Maximum	26.60	35.70	15.90	22.47	45.79	42.04	117.20

Note: 'Exp Con' denotes consumer expectation, and 'Exp Prof' – professional expectation; 'Food inf' represents food inflation and IPI – industrial production index.

Source: own elaboration.

ers. The wartime sample shows greater standard deviation, more dispersed mean expectations across time, and more forecasts below the mean, as indicated by positive skewness.

3. Methods applied

First, we analyse the dependencies between the expectations of consumers and professionals by entropy measures. We use mutual information, which quantifies the 'amount of information' obtained about one random variable by observing the other random variable (here—the degree of uncertainty dropped in expectations, assuming that inflation (or another macro variable) is known or the degree of uncertainty reduced in one group expectations as-

suming knowledge about expectations of the other group), and mutual conditional information, which expresses the mutual information of two random variables conditioned on a third (here, the degree of alignment of professional and consumer expectations excluding inflation or food inflation, industrial production index or exchange rate as a coordinating factor). The mutual information between two continuous random variables X, Y with probability destiny function $f(x)$ is given by equation (1):

$$I(X,Y)=\int_X\int_Y f(x,y)\log\frac{f(x,y)}{f(x),f(y)}dxdy \tag{1}$$

The mutual information has the following properties:

- symmetry: $I(X,Y)=I(Y,X)$,
- non negativity: $I(X,Y)\geq 0$,
- $I(X,Y)=0\Leftrightarrow X$ and Y are independent,
- $I(X,Y)$ is not bounded.

A normalised version of the mutual information was proposed by Linfoot (1957) as:

$$r(X,Y)=\sqrt{1-e^{-2I(X,Y)}} \tag{2}$$

and is called the information coefficient of correlation. In the following, all results are presented in a standardised version. Conditional mutual information between X, Y given Z with joint probability density $p_{X,Y}(x,y)$ is as follows:

$$I(X,Y\mid Z)=\int_X\int_Y\int_Z p_{X,Y,Z}(x,y,x)\log\frac{p_{X,Y,Z}(x,y,z)}{p_{X,Z}(x,z)p_{Y,Z}(y,z)}dxdydz \tag{3}$$

The conditional mutual information measures how much uncertainty is shared by X and Y, but not by Z.

In the case of continuous data, two estimation methods of the mutual information can be considered: (1) an estimation using discretisation, where the support sets of the random variables are discretised; (2) a nonparametric estimation without discretisation. In the study, we used the first method. Let X be a continuous random variable. We divide the interval of support set into k sub-intervals, called bins, with the following notation: n_k = the number of samples in bin k; N = the total number of samples; c = the total number of bins. The partition of the support set into sub-intervals provides each having the same number of data points.

After the discretisation of the variable, the entropy was estimated using an empirical estimator (Meyer, 2008):

$$H_{emp}=-\sum_{k=1}^{c}\frac{n_k}{N}\log\frac{n_k}{N} \tag{4}$$

We use the package *infotheo* (Meyer, 2014) for *R* programming to calculate entropy-based measures. The presented value is normalized mutual information, scored to scale the results between 0 (no mutual information) and 1 (perfect correlation). The mutual information denotes co-dependencies in two variables: non-linear relations between them. It indicates how much information can be obtained for a random variable by observing another random variable.

Next, we provide the distance measure using DTW algorithms, introduced in the literature by Vintsyuk (1968) and Sakoe and Chiba (1978), in both cases for speech applications. We consider two time series:

$C = \{c_1, c_2, ..., c_n\}$ and $Q = \{q_1, q_2, ..., q_n\}$ of length n and m, we construct an $n \cdot m$ distance matrix $D = (d(c_i, q_j))_{m \cdot n}$, where the entry $d(c_i, q_j)$ is the distance between points c_i and q_j. Then, we search for an optimal warping path ϕ, which minimises the accumulation of corresponding distance, subject to:

- continuity: given $\phi_k = (a, b)$ then $\phi_{k-1} = (a', b')$ where $a - a' \leq 1$ and $b - b' \leq 1$, which restricts the allowable steps in the warping path;
- monotonicity: given $\phi_k = (a, b)$ then $\phi_{k-1} = (a', b')$ where $a - a' \geq 0$ and $b - b' \geq 0$, which assure the points in to be monotonically spaced in time;
- boundary conditions: $\phi_1 = (1, 1)$ and $\phi_K = (m, n)$ and so the warping path starts and finishes in diagonally opposite corner cells of the matrix.

Dynamic time warping is invariant to time shifts, regardless of their temporal span. However, to ensure DTW remains sensitive only to local changes, constraints can be added to restrict the set of allowable paths. In this study, we apply windowing constraints suggested by Rutkowska and Szyszko (2022).

These procedures allow us to estimate not the distance between series in general but to approximate the degree of expectations orientation into the future or the past. Therefore, to measure the level of forward orientation, we search for the warping path only within the upper triangular distance matrix. Similarly, to measure the level of backward orientation, we use the lower triangular cost matrix, which is presented in Figure 2.

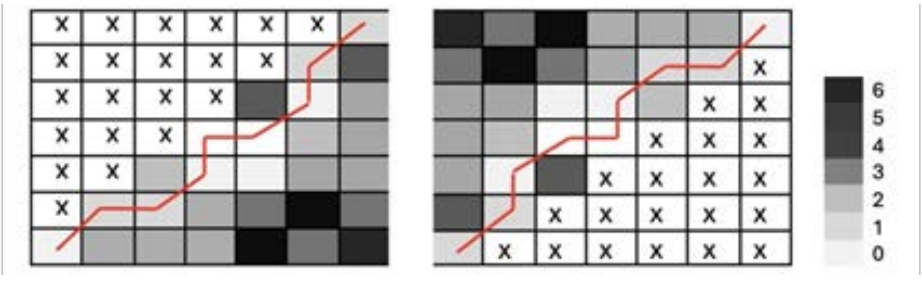

Figure 2. Distance matrix with optimal alignment and unacceptable area (marked with x) for backward (left panel) and forward (right panel) window

Source: own elaboration.

The notions of forward and backward orientations do not fully replicate the understanding of forward- and backward-lookingness as presented by standard methods (see Łyziak, 2014; Szyszko et al., 2020), based on the rationality tests, which are not applicable for the number of observations we have. The algorithm does not obey the standard lag structure when searching for the shortest distance between expectations and past or future inflation.

4. Results and discussion

The discussion of results starts with a mutual information analysis. Mutual information analysis presents the common information embedded within the expectations of professionals or consumers and inflation in Ukraine (see Figure 3 and Appendix Table A1) and the common information embedded within economic agents' expectations and industrial production index and exchange rate (see Figure 4 and Appendix Table A2).

When inflation is considered as a coordinating factor for professional expectation, we can conclude it matters less during the invasion, irrespective of the lags we discuss (see Figure 3). This result suggests that after the outbreak of war, professional forecasters in Ukraine reacted to information other than that on inflation to a greater extent than before the war. Increased macroeconomic uncertainty can encourage economic agents to put more effort into collecting data and forecasting, which is confirmed by micro-level analyses (Hope & Tony, 2005). This also aligns with the theoretical premises of bounded-rationality theories of expectation formation—economic agents become more attentive during turbulent times. They are ready for higher costs of acquiring and processing information (Mankiw & Reis, 2002). Bracha and

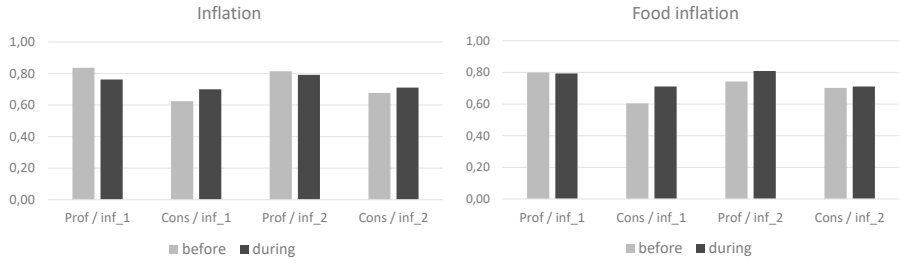

Figure 3. Mutual information between expectations and inflation

Note: 'Prof' denotes professional expectations, 'Con' – consumer expectations, 'inf_1' – 1M lagged inflation or food inflation, 'inf_2' – 2M lagged inflation or food inflation.

Source: own elaboration.

Tang (2022) confirmed this theory empirically for the U.S. However, it must be noted that this analysis does not allow us to conclude the causality between variables. It only describes co-movements whose desynchronization, as presented in Figure 1, could be due to many factors.

The jump in professional expectations just after the outbreak of war can be explained by understanding the extraordinary conditions and the effect of political shock on the economy's supply side and accounting for them in the inflation forecast. Food inflation was more important than inflation as a coordinating factor for professional expectations during the war when a 2M lag is considered. It is possible that professionals coordinated their expectations more with food inflation. Ukrainian consumers, who reported slightly higher alignment with inflation and food inflation after the invasion, could not process any extra information during increased uncertainty. However, the change in alignment for this group of economic agents is negligible, especially when a 2M lag is considered.

Mutual information between expectations and industrial production index decreased during the invasion for both groups of economic agents (see Figure 4 and Appendix Table A2). Still, the decrease was low. The assumption that during the war-related, severe economic downturn economic agents observed more closely production was not confirmed. It is worth noting that production data are published with the longest lag, and interpreting them in terms of the standard transmission mechanism is not so straightforward, especially for consumers with low economic literacy. When production collapses, the lower output gap transforms into lower inflation, as suggested by standard neo-Keynesian frameworks (Woodford, 2003). However, households do not recognise this relationship. Quite often, economic agents who

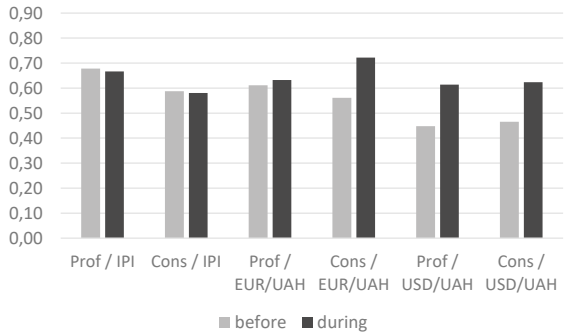

Figure 4. Mutual information between expectations and other economic variables

Note: 'Prof' denotes professional expectations, 'Con' – consumer expectations, IPI is 2M lagged, and exchange rates – are 1M lagged.

Source: own elaboration.

are more pessimistic about the economic outlook also exhibit greater pessimism about inflation and increase their forecasts for inflation. The effect of pessimism could be the case here, and transform into lower coordination between production and expectations after the war eruption.

An interesting observation can be made when mutual information between expectations and exchange rates is considered (see Figure 4 and Appendix Table A2). Knowing the exchange rate reduced the uncertainty in expectations during the war more than before it. This suggests that the NBU exchange rate policy was incorporated into expectation formation. Mutual information between professional expectations and USD/UAH rates increased more than for EUR/UAH rates when the US dollar became a nominal anchor for monetary policy. For consumers, the magnitude of change was comparable for both currencies.

When common information between expectations and inflation or other macro variables is compared, knowing inflation and food inflation has much more power to reduce expectations uncertainty than knowing production or exchange rates. Even if the exchange rate is considered an important coordinating variable for expectations in the Ukrainian economy, the focus on current inflation evolution prevails, as discussed in Section 2.

The next important question regarding expectation formation is the association between the expectations of different economic agents. Figure 5 and Appendix Table A3 present the results of the co-movement analysis between professional and consumer expectations. Common information increased after the outbreak of war.

More significant alignment is also reported for the conditional common information, regardless of which variable is excluded as the coordinating factor. In the conditional context, the results suggest that the alignment increases due to factors other than the common knowledge of the evolution of any of these specific variables. This means that co-movements could be driven by the general sentiments of professionals and consumers about the economic outlook. It is worth noting that when past inflation or food inflation is excluded, the change in coordination of expectations for pre-war and during-war subsamples is highest.

Even though the common information analysis suggested stronger links between past inflation or food inflation and expectations during the war for most of the cases, conditional mutual information suggests that during the war, other than past inflation, news transformed into a higher alignment of expectations between professionals and consumers. Still, if mutual and conditional mutual information are compared, the former is greater for all cases. This suggests that the common information embedded in professional and consumer expectations is primarily based on past inflation.

One of the most important questions regarding expectation formation is their alignment with past or expected inflation. In this study, we search for

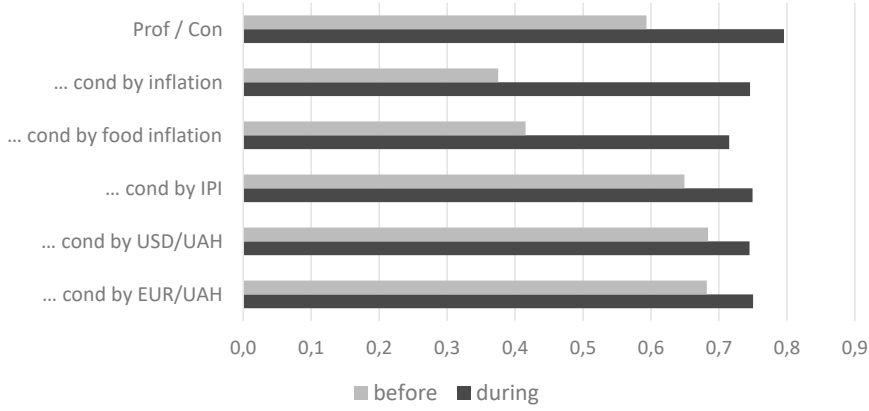

Figure 5. Mutual information and conditional mutual information between professional and consumer expectations

Note: 'Prof' denotes professional expectations, 'Con' – consumer expectations, 'cond' – conditioned by.

Source: own elaboration.

forward and backward orientation referring to actual inflation and food inflation. Figure 6 and Appendix Table A4 present the results of distance analysis returned by the DTW algorithm with the constraints on the windows (only forward or backward distance is considered). The values presented are distances divided by the number of observations of both series. The dynamic time warping provides a very good time series comparison. However, its distance is time series-dependent, and the values itself cannot be interpreted as big or low. Moreover, it shows the distance, which demonstrates the dissimilarity. If the forward distance is lower than the backward distance, expectations are more aligned with the future evolution of inflation.

As mentioned in Section 3, this understanding of forward and backward orientation differs from the standard approach, which compares expectations from period t only with past inflation from period t_{-1} or future inflation from period t_{+12}. DTW algorithm does not impose the constant lag structure. As a result, it returns the orientation for the past or future but is not understood in the same way as standard methods. It assumes that economic agents do not necessarily refer to a given period when forming expectations. DTW aligns sequences by finding the path that minimises the cumulative distance between the two sequences. This alignment allows for the non-uniform stretching and compressing of time in either sequence. The flexibility helps to match similar patterns that may occur at different speeds or be slightly shifted. Therefore, there is no fixed or constant lag across the entire sequence. Thus, if economic agents expect an inflation increase of several points, which occurs in the

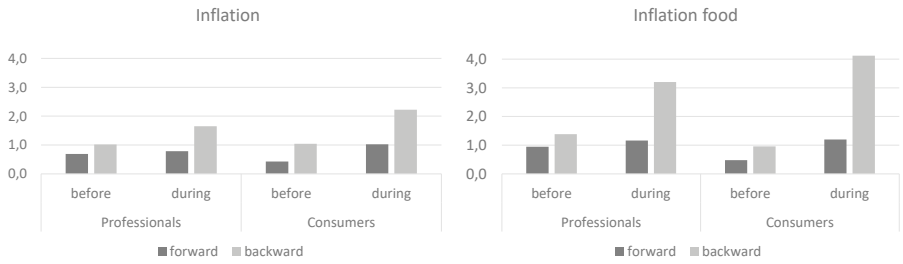

Figure 6. Distances between expectations and inflation or food inflation

Source: own elaboration.

next few months (and not necessarily equally in 12 months), their expectations are forward-oriented. If, on the other hand, they are least distant from past inflation, then they are backward-oriented.

A caveat is required here. For forward-looking analysis, the algorithm was constrained in measuring the forward distance. Expectations from March 2024 could be juxtaposed only with nine forthcoming instances of inflation or food inflation (from April to December 2024) due to the sample length.

A more forward- than backward-oriented approach is reported for Ukrainian economic agents before and after the war eruption, no matter whether we search for the distance between expectations and inflation or food inflation. This result is surprising. Ukrainian economic agents likely were more backward- than forward-looking before the invasion, as suggested by Zholud et al. (2019) and Lukianenko et al. (2022). However, the distance analysis provided in Table A4 reports shorter forward than backward distances for consumers and professionals before and during the invasion. It is worth noting that these distances increased during the war. The explanation could be linked to the importance of the exchange rate as an expectations driver. Before the invasion, Ukrainian consumers relied heavily on changes in the USD/UAH exchange rate when forecasting inflation (Coibion and Gorodnichenko, 2015). The NBU introduced restrictions on FX transactions and capital movements and fixed the USD/UAH exchange rate (NBU, 2022c), which could have affected the information consumers collect. This is in line with the observation provided by the conditional information analysis: inflation or food inflation became a much less coordinating factor for the expectations of consumers and professionals than other macro variables. Mutual information between expectations and exchange rates increased. It is worth noting that if food inflation is considered, the backward distance during the war increased more than for inflation. The change in forward distance was comparable regardless of whether food inflation was discussed.

DTW distances highlight another piece of information that the mutual information analysis offers. They refer to distances between the levels of time

series, whereas mutual information is a measure of the extent to which knowledge of one variable reduces uncertainty about the other. Thus, expectations may be more aligned with past inflation after the invasion and report higher backward distances as the difference in levels increases. This is the case in this study.

Conclusions

The paper provides the first empirical analysis of expectation changes in Ukraine, comparing their proprieties before and during the invasion. The study applies entropy measures and the dynamic time warping algorithm to provide a preliminary analysis of the change in expectations characteristics. Applying standard measures is not possible as the war sample is relatively short. Still, recognising expectation formation patterns is a crucial topic from a central bank perspective.

The results reported here confirm the change in expectations during the war (H1: The characteristics of economic agents' expectations in Ukraine are different during the war as compared to pre-invasion). Assuming the past inflation is known, the uncertainty reduction in expectations decreased in the case of Ukrainian professionals and increased for Ukrainian consumers. If inflation was replaced by food inflation, the uncertainty was reduced for consumers and professionals (for 2M lag). Mutual information, including conditional mutual information (assuming that inflation, food inflation, industrial production index or exchange rate is not a coordinating factor), increased during the invasion. The forward orientation towards inflation or food inflation of economic agents prevailed before and during the invasion, even though all the distances (forward and backward) were higher during the invasion. Thus, the second hypothesis (H2: During the war, economic agents are more oriented toward the future when forecasting inflation) was partially confirmed: professionals and consumers were more forward- than backward-oriented after the invasion, but during the war, the forward-looking distances were longer, which signals less accurate forecasts. Eventually, the coordination between professionals and consumers increased during the invasion (H3), even in a conditional context (excluding another macro variable as a coordinating factor).

From the central bank perspective, economic agents should be forward-looking or even rational to avoid their expectations being driven by past inflation during periods of surging inflation. The homogeneity of expectations among different economic agents also facilitates monetary policy, as its instruments are not selective. Forward orientation and co-movements of inflation expectations between consumers and professionals are good news

for central banks. As expectations did not rocket just after the invasion began (they were relatively stable and below the actual inflation rate), the NBU's fears regarding their evolution were not realised. Moreover, the central banks observe how expectations evolve regularly, paying much greater attention to them when a crisis occurs. This paper contributes to such monitoring under special circumstances by describing the changes or similarities in expectations behaviour after the invasion as compared to the pre-invasion period.

Several caveats should be made regarding the results of this study. Firstly, as usual, there is a tradeoff between the advantages of different methods. In this case, alternative methods were applied, which made it possible to conclude for a relatively short sample without any assumptions regarding the sample proprieties and length. By choosing this method, we need to abandon the greater comparability of the results with the existing studies and the possibility of a more straightforward interpretation. Secondly, during the research period of this study, global and domestic economies underwent rapid inflation surges, which then decreased. The inflation trends and not only war-related factors could affect how expectations are formed. However, while past studies justified choosing the date of the invasion as the breakpoint in inflation, the causal analysis requires a longer sample.

Appendix

Table A1. Mutual information between expectations and inflation

Subsample	Prof / inf_1	Cons / inf_1	Prof / inf_2	Cons / inf_2
Inflation				
Before war	0.8356	0.6242	0.8143	0.6763
During war	0.7621	0.6991	0.7912	0.7107
Food inflation				
Before war	0.7986	0.6041	0.7428	0.7018
During war	0.7939	0.7107	0.8090	0.7107

Note: 'Prof/inf' refers to mutual information between professional expectations and inflation; 'Con/inf' between consumer expectation and inflation; 'inf_1' denotes inflation or food inflation lagged by 1M; 'inf_2' denotes inflation or food inflation lagged by 2M.

Source: own elaboration.

Table A2. Mutual information between expectations and other variables

Subsample	Industrial production index	EUR/UAH	USD/UAH
	Professionals		
Before war	0.6781	0.6116	0.4479
During war	0.6671	0.6323	0.6135
	Consumers		
Before war	0.5877	0.5610	0.4653
During war	0.5805	0.7222	0.6240

Source: own elaboration.

Table A3. Mutual and conditional mutual information between professional and consumer expectations

		Before war	During war
Prof / Con		0.5932	0.7959
Prof / Con conditioned on:	Inflation	0.3753	0.7458
	Food inflation	0.4153	0.7150
	Industrial production index	0.6492	0.7494
	USD/UAH	0.6839	0.7452
	EUR/UAH	0.6823	0.7502

Source: own elaboration.

Table A4. Distances between expectations and inflation

		Forward	Backward	Backward--forward
Inflation	Consumers			
	before	0.4294	1.0397	0.6103
	during	1.0215	2.2227	1.2012
	Professionals			
	before	0.6904	1.0208	0.3304
	during	0.7874	1.6476	0.8602
Food inflation	Consumers			
	before	0.4809	0.9603	0.4794
	during	1.1993	4.1213	2.9220
	Professionals			
	before	0.9468	1.3865	0.4397
	during	1.1625	3.2020	2.0395

Note: 'Backward' measures the distance between expectations and past inflation; 'Forward' represents the distance between expectations and future inflation.

Source: own elaboration.

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Financial inclusion, market concentration and underwriting performance: Empirical evidence from Central Eastern and Southeastern European countries

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Abstract

Synergies or trade-offs may arise between financial inclusion and financial stability, depending on the type of financial market and the level of market competition. We focus on the less inclusive and less competitive Central Eastern and Southeastern European non-life insurance markets and examine the link between financial inclusion and insurers' underwriting performance and whether the insurance market concentration affects the inclusion-performance nexus. We use two measures of financial inclusion in insurance, one measuring the availability of insurers and the other measuring the aggregate insurance premium volumes. The results suggest that the impact of inclusion on underwriting performance is conditional on how inclusion is measured and

Keywords

- insurance
- financial inclusion
- market concentration
- underwriting performance

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on the prevailing market structure. These findings highlight the need for further research but also suggest that policy efforts aimed at fostering more inclusive insurance markets should consider the structural characteristics of insurance markets to ensure effective outcomes for consumers, insurers, and regulators.

JEL codes: G22, I31, L10, O52

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Introduction

Financial inclusion has become a high-priority commitment for governments around the world and has been identified as an important means to achieving Sustainable Development Goals (SDGs), especially poverty alleviation (World Bank, 2018). Greater access to and use of financial services, such as savings, bank credit, insurance and payments, help reduce poverty and income inequality (Jungo et al., 2022c). While financial inclusion has a positive influence on important economic outcomes, it may have destabilising effects on financial systems. As access to financial services increases for less sophisticated consumers and businesses, financial institutions face higher costs in reaching these consumers and businesses, which may result in increased vulnerabilities in the interconnected financial system (Čihák et al., 2021; Feghali et al., 2021).[5] The current literature focuses primarily on the banking sector and examines the link between financial inclusion and financial stability, thereby neglecting the potential influence on the insurance sector (e.g., Chinoda & Kapingura, 2023; Feghali et al., 2021; Jungo et al., 2022b).

The demand for (micro) insurance in low-income countries remains low despite the expectation of higher take-up rates driven by the exposure to frequent adverse events in those environments where risk transfer options are limited (Platteau et al., 2017). Current evidence shows that financial exclusion and liquidity constraints hinder demand for insurance (Luciano et al., 2016; Platteau et al., 2017). Additionally, some individuals and businesses may be excluded because of supply-side factors. Due to the potentially higher costs (adverse selection and moral hazards) in dealing with riskier consumers and businesses, insurers may opt to limit the supply of insurance services. Such behaviour more likely arises in more concentrated insurance markets,

[5] An alternative view is that financial inclusion provides diversification benefits for financial institutions contributing to greater financial stability (e.g., Čihák et al., 2021; Han & Melecky, 2013; Hanning & Jansen, 2010, Jungo et al., 2022b).

in line with the structure-conduct-performance (SCP) hypothesis (Bajtelsmit & Bouzouita, 1998; Chidambaran et al., 1997; Cole et al., 2015; Pope & Ma, 2008). Thus, more concentrated markets may be associated with lower access and use of insurance services, resulting in a more profitable and stable insurance market. Alternatively, larger insurers in more concentrated markets may be prone to risky behaviour and acquire less sophisticated consumers and businesses, leading to greater vulnerabilities (e.g., Shim, 2017). Hence, the interplay between financial inclusion and market concentration is ambiguous but pivotal to insurers' profitability and stability.

The aims of this paper are, firstly, to examine the link between financial inclusion and insurers' underwriting performance and, secondly, to establish whether insurance market concentration affects the relationship between financial inclusion and the underwriting performance of insurance markets. We use country-level data and focus on a sample of Central Eastern and Southeastern European countries(CESEE). Over the past three decades, the insurance markets in these countries have undergone significant transformations, including privatisation, deregulation, and liberalisation. These changes aimed to align the CESEE insurance sector with European Union (EU) standards, particularly for countries that have joined or aspire to join the EU (Njegomir & Stojić, 2012). Regulatory adjustments were made to comply with EU frameworks, such as Solvency I and Solvency II, fostering integration and market development (Njegomir & Stojić, 2011). However, despite these efforts, substantial cross-country disparities persist in insurance market development (Born & Bujakowski, 2019). While financial inclusion has improved, concerns remain in several CESEE countries where account ownership rates and insurance penetration lag behind those in more developed European countries (Demirgüç-Kunt & Muller, 2019). A dearth of insurer-level data has hampered the research on Central Eastern and Southeastern European insurance markets. However, XPRIMM's premium and claim database allows for greater region and time coverage (Born & Bujakowski, 2022). We extract data from the International Monetary Fund Financial Access Survey (FAS) to measure the level of financial inclusion, while we construct variables for market concentration and insurers' (underwriting) performance from the XPRIMM's premium and claims database. To test our hypotheses, we employ instrumental variables panel data regression analysis to control potential endogeneity issues.

This paper contributes to at least two domains of research. Firstly, the current literature is mainly concerned with how financial inclusion affects bank stability (e.g., Chinoda & Kapingura, 2023; Feghali et al., 2021; Jungo et al., 2022b) and the mediating effects of bank market competitiveness (e.g., Beck et al., 2004; Jungo et al., 2022a; Owen & Pereira, 2018; Rosengard & Prasetyantoko, 2011). However, the greater access to and use of financial services may stimulate demand for insurance from less sophisticated consum-

ers and businesses, which has implications for the stability and profitability of insurers. Secondly, the interplay between financial inclusion and market concentration may have diverse impacts on insurers' stability and profitability. The extant literature focuses on the direct relationship between market concentration and insurers' stability and performance without considering potential mediating variables (e.g., Bajtelsmit & Bouzouita, 1998; Chidambaran et al., 1997; Cole et al., 2015; Pope & Ma, 2008; Shim, 2017). However, the increase in those having access to financial services affects insurers' decisions on whether to compete and absorb the increase in demand, resulting in a riskier portfolio or restricting the supply of insurance services, securing monopoly profits in the absence of strong competition.

Finally, the study provides policy implications relevant for the insurance regulators and policymakers in the Central Eastern and Southeastern European countries. Initially, if a trade-off emerges between financial inclusion and stability, then policies geared at stimulating higher financial inclusion should be accompanied by a resilient regulatory approach to prevent vulnerabilities in the insurance sector. Alternatively, the concentrated insurance markets may limit the effectiveness of policies aimed at increasing financial inclusion as insurers utilise their market power to restrict the supply of insurance services. On the other hand, financial inclusion may expand the market and increase the competitiveness of the insurance sector, leading to more efficient and stable insurers. In such a case, the policy efforts for more inclusive financial markets would generate improved outcomes for consumers, insurers, and regulators.

This article proceeds as follows: in the next section, we review the existing literature on the effects of financial inclusion and market competition on financial stability and insurers' performance. This is followed by a development of the hypotheses about the relationship between financial inclusion, market competition and insurers' performance and by a description of the data and methodology used to empirically test our hypotheses, and a section containing our results. The final section provides conclusions.

1. Literature review and hypotheses development

1.1. Market concentration and insurer stability

Insurance literature examines the effects of market concentration on insurer stability and performance. Drawing from the industrial organisation literature, researchers devised two competing views.[6] The competition-fragility view as-

[6] See Shim (2017).

sumes that excessive competition in insurance markets reduces profit margins, prompting riskier behaviour of insurers and deteriorated insurer stability (e.g., Keeley, 1990). This view is also consistent with the structure-conduct-performance hypothesis, which states that insurers in more concentrated markets have the power to restrict supply or raise prices, achieving higher profits and stability. Several studies find support for the competition-fragility hypothesis: Shim (2017) for the US property-liability insurance market, Cummins et al. (2017) for the European life insurance market, and Altuntas and Rauch (2017) for the global property-liability insurance market. Additionally, the literature provides support to the structure-conduct-performance hypothesis for non-life insurance markets (e.g., Bajtelsmit & Bouzouita, 1998; Chidambaran et al., 1997; Cole et al., 2015; Janků & Badura, 2021; Pope & Ma, 2008).

Alternatively, the competition-stability view states that large insurers, expecting a government bailout in case of financial difficulties, hold lower capital buffers and tend to undertake riskier actions (e.g., Kasman et al., 2020), while stronger competition causes price reductions and affordable insurance products, mitigating the adverse selection and moral hazard problems through a more diversified customer base resulting in higher insurer stability. Kasman et al. (2020) provide support for both the competition-stability and competition-fragility hypothesis for Türkiye's non-life insurance market. Additionally, Alhassan and Biekpe (2018) and Janků and Badura (2021) discover a non-linear relationship between market concentration and insurer stability and performance in the South African and European non-life insurance markets, respectively. The evidence of the non-linear relationship between market concentration and insurer stability may indicate mediating effects of potentially omitted variables.

1.2. Financial inclusion and financial stability

The extant literature recognises that the complex relationship between financial access and financial stability depends on sectoral differences as well as market competitiveness, and focuses primarily on the banking sector, in doing so neglecting the relationship between financial inclusion, market competitiveness and stability in the insurance sector. The researchers provide two opposing views regarding the relationship between financial inclusion and financial stability. One strand of the literature claims that financial inclusion provides stabilising benefits for the financial system by instigating deeper and more diversified financial systems, providing greater resilience in normal and crisis periods, and reducing the exposures of financial institutions. For instance, Hanning and Jansen (2010) argue that financial inclusion reshapes financial markets by introducing new lines of business without increasing the systemic

risk due to the idiosyncratic nature of microfinance business lines and proper regulation and supervision related to those lines of business. Additionally, financial inclusion enhances a resilient banking system during crises by mitigating deposit withdrawals (Han & Melecky, 2013) and limiting the declines in credit and borrower growth rates (López & Winkler, 2019). Also, Čihák et al. (2016) find that financial inclusion contributes to financial stability in normal times by decreasing through-the-cycle expected losses and costs of business for banks. Finally, broader access to financial services reduces credit risk and improves bank efficiency. For instance, Jungo et al. (2022b) find that financial inclusion reduces credit risk in sub-Saharan African countries, while Chinoda and Kapingura (2023) find that digital financial inclusion correlates negatively with non-performing loan rates. Lastly, Ahamed & Mallick (2019) argue that financial inclusion improves bank stability by boosting bank operating efficiency. Given the parallels between banking and insurance in terms of risk management, financial intermediation, and market dynamics, insights from the banking sector can offer valuable perspectives on how financial inclusion may influence stability in the insurance industry, particularly regarding risk diversification, market resilience, and operational efficiency.

The other strand of the literature argues that there is a trade-off between financial inclusion and financial stability. This trade-off would probably materialise via increasing the risk-taking behaviour of less sophisticated, low-income individuals, especially concerning greater access to credit, which may instigate unexpected losses for banks. Čihák et al. (2016, 2021) claim that greater access to credit accelerates consumer credit growth, resulting in substantial systemic risk, which may lead to banking crises. However, the authors find that synergies arise between financial inclusion and financial stability concerning greater access to saving and insurance products. By using a large panel of over 100 countries, Feghali et al. (2021) confirm that bank stability is negatively related to greater credit access while positively related to greater savings and payment access.

The recent literature on the inclusion-stability nexus uncovers two important mediating effects of competitiveness in the financial sector. Firstly, financial institutions may exert their market power to expand their customer base and reduce marginal costs (via scale economies), resulting in greater financial stability. Ahamed and Mallick (2019) find positive effects of financial access on bank stability for high-market-power banks.[7] Alternatively, greater market competitiveness may relax the population's access to financial services, inducing financial institutions to take higher risks, resulting in deteriorated financial

[7] Two additional studies, Chinoda and Kapingura (2023) and Jungo et al. (2022b), discuss the potential interaction effects between financial inclusion and bank competitiveness on bank stability, although they do not test this directly by including interaction terms. Both studies find a negative relationship between market competitiveness and bank stability.

stability. In this regard, Feghali et al. (2021) find that the negative effects of credit inclusion on bank stability are enhanced in more competitive markets.

1.3. Hypotheses development

Information asymmetry between insurers and policyholders regarding the insured's risk profile presents a fundamental challenge in designing insurance contracts (e.g., Rothschild & Stiglitz, 1978). Since risk levels are private information, insurers must rely on mechanisms that induce policyholders to self-select into contracts that reflect their true risk profile (e.g., Salop & Salop, 1976). Rothschild and Stiglitz suggest that insurers achieve this by offering differentiated combinations of premiums and deductibles, encouraging the separation of high-risk and low-risk customers. In underdeveloped Central Eastern and Southeastern European insurance markets, self-selection mechanisms may not function effectively due to limited financial literacy, weak enforcement of risk-based pricing, and data constraints that hinder accurate risk assessment. Additionally, high market concentration reduces competitive pressures to develop differentiated contracts, while regulatory restrictions and consumer distrust further limit insurers' ability to incentivise policyholders to reveal their true risk profiles. As a result, insurers may rely on broad pricing strategies or supply restrictions rather than sophisticated self-selection mechanisms, weakening the potential benefits of financial inclusion on underwriting performance.

Greater financial inclusion broadens access to insurance services for less financially sophisticated consumers and small businesses. While this expansion can introduce higher acquisition and underwriting costs, it also allows insurers to diversify their risk pool. If low-risk individuals predominate among newly gained customers, insurers benefit from a broader, more stable risk distribution, enhancing underwriting performance through lower loss ratios.[8] However, if the newly included population is dominated by high-risk individuals, such financial inclusion may fail to improve underwriting performance, due to the greater exposure to adverse selection and moral hazard. Moreover, low-income, high-risk individuals may remain uninsured or underinsured as a result of the limited expected benefits relative to costs, further influencing the overall effect of financial inclusion on insurer profitability.[9]

[8] Ahamed and Mallick (2019) find that banks with larger pool of customers with respect to retail deposits tend to be more stable in the inclusive financial sector by reducing the costs and risks.

[9] Insurance contracts may not provide the expected payout for customers for every potential loss. Thus, insurance demand may be lower, especially for index-based insurances, where the insurance payouts are based on an index (Clarke, 2016).

Market structure plays a critical role in shaping the relationship between financial inclusion and underwriting performance. In highly concentrated markets, insurers may strategically limit coverage for low-income, high-risk consumers, thereby reducing the potential benefits of financial inclusion on underwriting performance. In contrast, more competitive markets encourage price reductions and the development of affordable insurance products, facilitating broader access for low-income consumers. This increased access can mitigate adverse selection and moral hazard by fostering a more diversified customer base, reinforcing the positive effects of financial inclusion on insurers' underwriting performance. In Central Eastern and Southeastern European (CESEE) countries, the structure-conduct-performance (SCP) hypothesis is more likely to hold due to high market concentration, regulatory constraints, and limited competitive pressures. Many insurance markets in the region are dominated by a few large firms, often former state-owned enterprises or subsidiaries of multinational insurers, enabling them to impose supply restrictions and sustain higher prices rather than compete on efficiency. Strict EU regulatory requirements, such as Solvency I and Solvency II, create high compliance costs that act as entry barriers, further limiting competition. Additionally, low consumer mobility, lack of price transparency, and historical legacies of state-controlled monopolies reduce competitive dynamics, allowing dominant insurers to exercise market power. Thus, our analysis is guided by two hypotheses:

H1: A higher level of financial inclusion improves the underwriting performance of non-life insurers through reduced loss ratios.

H2: The positive effect in H1 on underwriting performance is expected to be lower in more concentrated insurance markets, where insurers have the power to impose supply restrictions or raise rates.

2. Data and methodology

2.1. Sample and data

To test our hypotheses, we analyse a sample of Central Eastern and Southeastern European countries, including both European Union (EU) member states and EU candidate countries. Our sample consists of countries from Central and Eastern Europe (CEE) and Southeastern Europe (SEE), encapsulating the Western Balkans, Türkiye, and Georgia as EU candidate countries. Specifically, the CEE subregion includes EU member states such as the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, and Slovenia, which have relatively more developed financial systems and higher levels of finan-

cial inclusion due to their longer EU membership and economic integration. In contrast, the SEE subregion, comprising Bulgaria, Croatia, Cyprus[10], as well as the Western Balkans—Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, and Serbia—exhibit greater variation in financial inclusion and market development. Additionally, our sample includes EU candidate countries, such as Georgia, Moldova, Ukraine, and Türkiye, which have distinct economic structures and financial sector developments.

While these countries share a common objective of aligning their financial regulations with EU standards, they exhibit substantial heterogeneity in financial inclusion and insurance market concentration. Financial inclusion levels vary widely across the region; for instance, account ownership rates remain unsatisfactory in many countries (e.g., Demirgüç-Kunt & Muller, 2019), and the proportion of individuals who saved any money in the past year is even lower, indicating that while some have bank accounts, they do not actively use them for savings (Feghali et al., 2021). This disparity suggests that financial infrastructure development and utilisation differ significantly within the region.

In addition, the degree of foreign investor presence and its impact on market concentration is uneven across countries. The strong presence of foreign affiliates in certain markets underscores the region's relevance within the fragmented European insurance industry, yet this influence is not uniform. As presented in Table 1, the average Herfindahl-Hirschman Index (HHI) exceeds 1300, indicating a relatively high market concentration.[11] However, significant variations exist, with some countries having more competitive insurance markets than others. Similarly, insurance density, measured by the inflation-adjusted Gross Written Premium per capita, averages 210.3 US dollars but fluctuates considerably across the sample, reinforcing the heterogeneity in market development. Table 1 provides detailed descriptive statistics on these variations, supporting our argument that while regulatory frameworks align, financial inclusion and market structures remain diverse, making this heterogeneity a crucial aspect of our analysis.

To construct our main dependent variable, loss ratio (LR), we collect non-life premium and claim data from XPRIMM's database for 19 countries over the period 2010–2021. The complete list of countries is included in Table A1 in the Appendix. The loss ratio shows the total technical outflows related to claim settlement activities as a measure of underwriting profitability (Janků & Badura, 2021). We calculate it with country-level data as a ratio of claims paid

[10] We had to exclude Romania from the sample due to missing claim data.

[11] The Herfindahl-Hirschman index is the sum of the squared percentage market share for non-life insurance for each insurer in the country. Market share is defined as the proportion of total non-life premiums accounted for by each insurer in the country based on gross non-life premium written.

We additionally used the percentage share of the top 3 insurers' premiums in total premiums and the Theil index. The regression results remain qualitatively similar.

to gross premiums written. A persistently high loss ratio may indicate that insurance companies are facing financial difficulties (Kwon & Wolfrom, 2017).

Table 1. Descriptive statistics

Variable	Obs.	Mean	Standard deviation	Minimum	Maximum
Loss ratio (LR) (%)	203	49.553	11.875	19.613	93.904
Insurers per 100,000 adults (ICPOP)	203	0.914	0.709	0.1	3.63
Real Gross Written Premium Per Capita (RGWPPC)	203	210.294	212.003	20.055	1014.191
Herfindahl Hirschman Index (HHI)	203	1398.366	545.044	323.375	2974.358
Economic Development (EDEV)	203	9.037	.721	7.661	10.253
Population (POP)	203	15.333	1.151	13.336	18.223
Financial Development (FDEV) (%)	203	57.002	34.991	22.762	254.668
Openness (OPEN) (%)	203	114.881	29.459	48.328	170.76
Inflation (INFL) (%)	203	2.859	4.38	–2.097	48.7
Governance (GOV)	203	15.966	9.666	–2.805	35.125
Agriculture (AGRIVA) (%)	203	5.945	4.312	1.541	19.99
Population density (POPDEN)	203	81.92	30.515	30.24	138.576

Source: own calculations.

We use two measures of financial inclusion, which relate to the insurance aspect of financial inclusion: Firstly, we extract data for the number of insurance corporations per 100,000 adults (variable: ICPOP) from the International Monetary Fund Financial Access Survey (FAS),[12] which is available yearly and relates to the supply side of finance. Secondly, we extract data about Gross Written Premium from the XPRIMM database and inflation and population data from the World Bank database to construct an inflation-adjusted Gross Written Premium per capita, constant 2010 US dollars (variable: RGWPPC). Table A2 in the Appendix contains a detailed description of the variables and the sources.

The selected measures (ICPOP and RGWPPC) gauge financial inclusion in insurance, but they may capture different dimensions. Conceptually, ICPOP is a supply-side indicator—a measure of insurer availability relative to the population—whereas GWP per capita reflects insurance demand, indicating how much the average individual spends on insurance. In other words, a higher ICPOP signifies more insurance providers accessible per adult (greater out-

[12] Researchers tend to devise a financial inclusion index from a wide set of indicators available in the IMF FAS database (e.g., Jungo et al., 2022b).

reach and competition), while a higher GWP per capita denotes greater insurance usage or density (higher premiums written per person, often tied to income levels). These differences may mean the two measures do not always move together. As such, a country can have many insurers relative to its population but still low average premiums (if consumers buy very little insurance) or, conversely, few insurers but high average premiums (if a concentrated market sells relatively expensive policies). Given these differences, ICPOP may emerge as a more appropriate measure of financial inclusion because it directly gauges the breadth of the insurance supply in each country and thus better captures the extent to which consumers have access to insurance services. In contrast, GWP per capita, while useful as an aggregate penetration metric, does not distinguish whether premiums are coming from a broad base of policyholders or just a narrow segment. Thus, we take ICPOP as our main proxy for inclusion, and we use GWP per capita as a robustness check.

Finally, we devised a set of control variables. The inclusion of control variables will capture the independent effects on insurer performance, mitigating the omitted variable bias problem. The set of controls comprises: natural logarithm of real Gross Domestic Product per capita (measure of economic development), natural logarithm of population (measure of demographics and market size), share of domestic credit to private sector as a percentage of Gross Domestic Product (measure of financial development), trade as a percentage of Gross Domestic Product (measure of openness), inflation rate (measure of economic (in)stability), governance (measure of institutional development) measured by the principal component of the six measures in Kaufmann et al. (2011) (see Table A2 in the Appendix for more details on variables construction).[13]

2.2. Methodology

We employ panel data regression analysis to avoid the weaknesses of possible serial correlation, which may arise in the pooled OLS regressions. Fixed-effects and random-effects regressions possess certain weaknesses. While the fixed-effects approach captures only within effects abstracting from the time-invariant variations, the random-effects approach implicitly assumes that the within (longitudinal) and between (cross-sectional) effects are identical (Bell & Jones, 2015). Thus, based on Mundlak (1978), Bell and Jones (2015) developed an approach to separate within and between effects. They suggest a group mean centring in which a variable is transformed by subtracting

[13] We follow Feghali et al. (2021) and include a similar set of control variables. Additionally, we extend the control set with inflation and trade openness as important determinants of non-life insurance development (e.g., Sawadogo et al., 2018).

the average over time from the original variable and including the time-averaged variables in the regression before running a random-effects estimation. Accordingly, we develop the following regression equation to test our hypotheses:

$$\begin{aligned} LR_{it} = \beta_0 + \beta_1(FI_{it} - \overline{FI_i}) + \beta_2\overline{FI_i} + \beta_3(FI_{it}\cdot HHI_{it} - \overline{FI_i}\cdot\overline{HHI_i}) + \\ + \beta_4(FI_i\cdot\overline{HHI_i}) + \beta_5(HHI_{it} - \overline{HHI_i}) + \\ + \beta_6\overline{HHI_i} + f'(X_{it} - \overline{X}_i) + \delta'\,\overline{X}_i + d_t + v_{it} \end{aligned} \quad (1)$$

where LR_{it} is the loss ratio for the country i and year t, FI_{it} is one of the financial inclusion proxies, HHI_{it} is the Herfindahl Hirschman index, X_{it} is a matrix of control variables, d_t is the year dummy, v_{it} is the error term, and the bar notation for each variable serves to designate the time-averaged data. Thus, the β_1, β_3 and β_5 capture the within effect, while β_2, β_4 and β_6 is the between effect for our main variables.

However, random-effects ordinary least squares (OLS) estimation does not resolve endogeneity issues arising from reverse causality and omitted variables. As Morgan and Pontines (2018) argue, that the relationship between financial inclusion and financial stability may mean that more stable financial markets provide greater access to finance for individuals and businesses. Thus, primarily we opt to estimate ordinary least squares regressions and then implement a more robust estimation strategy by employing random effects two-stage least squares regressions using instrumental variables (IV-2SLS) to control for the endogeneity issues.

For a proper identification strategy, we must decide on the treatment of the main independent variables and the selection of a proper instrument list. As stated previously, we treat financial inclusion variables as endogenous; thus, every interaction term with the FI_{it} results in endogenous variables. In that case, the estimation of within-between random-effects with instrumental variables (WBRE-IV) represent systems nonlinear in endogenous variables. Such a system requires a different or extended set of instruments for proper identification. Wooldridge suggests a general approach to dealing with nonlinear systems in endogenous variables through the inclusion of squares and cross-products of the exogenous variables (e.g., Michler et al., 2019).

We select two instruments to control for the endogeneity issues between financial inclusion and insurer performance: population density (population per squared kilometre of land area) (POPDEN) and the percentage share of agriculture, forestry, and fishing value added in GDP (AGRIVA). Higher population density drives greater access to finance through cost reductions caused by economies of scale effects and the elimination of distances (Alter & Yontcheva, 2015; López & Winkler, 2019). Additionally, agriculture emerges as an important determinant of financial inclusion (e.g., Evans, 2018). While

agricultural workers are generally underinsured, improved agricultural productivity increases the affordability and importance of insurance products for agricultural workers via greater output being at risk. We use the following extended set of squared and interaction terms of exogenous variables: the percentage share of agriculture, forestry, and fishing value added in GDP (AGRIVA), the percentage share of agriculture, forestry, and fishing value added in GDP squared ($AGRIVA^2$), the product of the percentage share of agriculture, forestry, and fishing value added in GDP and the Herfindahl Hirschman Index (AGRIVA*HHI), the population density (POPDEN), the population density squared ($POPDEN^2$), and the product of the population density and the Herfindahl Hirschman Index (POPDEN*HHI). To check for the consistency of the regressions, we use an overidentifying restrictions test (Hansen J-statistic).[14]

Finally, we decided to treat the Herfindahl-Hirschman Index as an exogenous variable for the following reasons: Firstly, the primary aim of this analysis is not to examine the concentration-performance relationship in the insurance industry but to provide evidence of how the relationship between financial inclusion and insurer performance differs depending on the extent of market concentration. Secondly, the treatment of the Herfindahl-Hirschman Index as an endogenous variable would complicate the analysis and interpretation of the results due to the need to include a new set of instruments. Lastly, the structure-conduct-performance hypothesis presumes that market structure is exogenously given in determining market performance (e.g., Cole et al., 2015).

3. Empirical results

We start our analysis by running within-between random-effects (WBRE) models without (OLS) and with (IV) instrumental variables, using the number of insurance corporations per 100,000 adults as a proxy for financial inclusion (Equation 1). Table 2 presents the estimates of the within effect (corresponding to the transformed variables DeavgICPOP, DeavgICPOP*HHI, and DeavgHHI) and between effect (corresponding to the time-averaged variables AvgICPOP, AvgICPOP*HHI, and AvgHHI). The coefficient of the group-mean-centred number of insurance corporations per 100,000 adults (DeavgICPOP) is insignificant, regardless of the chosen specification. Given that the variation in this variable is sluggish over time, it is less likely to capture any time effects of financial inclusion on insurer performance. On the other hand, the time-av-

[14] The null hypothesis is that the instruments are valid instruments, i.e. uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation.

eraged number of insurance corporations per 100,000 adults (AvgICPOP) is negative, but only significant at a 5 percent level in the regressions with interaction terms. Also, the results of the between-effect are robust in the IV regressions. The interaction term, the time-averaged product of the number of insurance corporations per 100,000 adults and the Herfindahl Hirschman Index (AvgICPOP*HHI) is positive and statistically significant at a 5 percent level. The insignificance of the coefficient of financial inclusion in the regressions without interaction terms suggests that the relationship between financial inclusion and insurer performance is complex and non-linear.

We fail to find support for the first hypothesis of a linear relationship existing between financial inclusion and underwriting performance. Rather, the results suggest that greater financial inclusion improves the performance of non-life insurers through lower loss ratios, although the relationship depends on the level of market competitiveness. The positive coefficient of the interaction term indicates that the positive effects of financial inclusion on insurer performance are stronger in the markets with lower levels of market concentration (higher competitiveness). Additionally, the between effect of HHI is consistently negative and significant at a 5 and 10 percent level (see Table 2), supporting the structure-conduct-performance hypothesis conditional on the level of financial inclusion.[15]

The Wald Chi-squared statistic shows that the within-between random-effects regressions are estimated correctly. The results of the Hansen test show that the instruments are exogenous. The test statistics are insignificant, showing that instruments are not correlated with the error term. In summary, the diagnostic tests suggest that the instruments and models are correctly specified.

Additionally, we estimate Equation 1, with the real Gross Written Premium (GWP) per capita as a measure of financial inclusion, using the within-between random effects panel data method without and with instrumental variables. Table 3 reports the results of the ordinary least squares (WBRE OLS) and two-stage least squares with instrumental variables (WBRE IV) regressions. Similarly, we fail to find significant within effects, as the coefficient of the group-mean-centred real GWP per capita (DeavgRGWPPC) is negative but insignificant. Considering the between effects, we observe surprising results as the coefficient of the time-averaged real GWP per capita (AvgRGWPPC) is positive and statistically significant at a 1 percent confidence level. However, after the inclusion of the interaction term, the coefficients become insignificant. These apparently contradictory results may suggest that the real GWP

[15] Additionally, we performed separate analyses for the EU and non-EU groups. Although the results lost statistical significance, the coefficients for the between effects maintained their direction. Despite the lack of significance, the findings suggest that the variation in the non-EU group primarily drives the between effects.

Table 2. Relationship between financial inclusion, market concentration and loss ratio (ICPOP variable)

Method	WBRE (OLS)	WBRE (OLS)	WBRE (IV)	WBRE (IV)
Dependent variable	**Loss ratio**	**Loss ratio**	**Loss ratio**	**Loss ratio**
DeavgICPOP	–2.027	–3.145	7.366	–21.323
	(–0.219)	(–0.333)	(0.155)	(–0.929)
DeavgICPOP*HHI		0.001		–0.002
		(0.210)		(–0.153)
DeavgHHI	–0.002	–0.004	–0.002	–0.002
	(–0.751)	(–0.699)	(–0.566)	(–0.214)
AvgICPOP	–6.347	–29.080**	–5.060	–28.937**
	(–0.838)	(–2.181)	(–0.693)	(–2.156)
AvgICPOP*HHI		0.009**		0.009**
		(2.086)		(2.068)
AvgHHI	–0.002	–0.011**	–0.002	–0.011*
	(–0.492)	(–2.000)	(–0.613)	(–1.958)
Constant	81.12	122.88**	71.79	121.86**
	(1.201)	(2.325)	(1.097)	(2.331)
Observations	203	203	203	203
# of Countries	19	19	19	19
Time dummies	**Included**	**Included**	**Included**	**Included**
Wald Chi-squared	246.2	284.34	343.3	2397
R-squared (between)	0.719	0.771	0.722	0.765
Hansen *J*-statistics (*p*-value)			0.3212	0.7084

Note: All models are estimated using the Within-Between Random-Effects (WBRE) panel data method using the xtreg/xtivreg command in STATA. The financial inclusion variable, the number of insurance corporations per 100,000 adults (ICPOP) and the interaction term between the number of insurance corporations per 100,000 adults and Herfindahl Hirschman index (ICPOP*HHI) are treated as endogenous in the IV models. The instruments are the percentage share of agriculture, forestry, and fishing value added in GDP (AGRIVA), the percentage share of agriculture, forestry, and fishing value added in GDP squared ($AGRIVA^2$), the product of the percentage share of agriculture, forestry, and fishing value added in GDP and the Herfindahl Hirschman Index (AGRIVA*HHI), the population density (POPDEN), the population density squared ($POPDEN^2$), and the product of the population density and the Herfindahl Hirschman Index (POPDEN*HHI). The prefix *Deavg* designates the group-mean-centred variables (within effects), and the prefix *Avg* designates the time-averaged variables (between effects). The within and between effects of the control variables are estimated but not displayed in this table for matters of convenience. Robust z-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: own calculations.

Table 3. Relationship between financial inclusion, market concentration and loss ratio (RGWPPC variable)

Method	WBRE (OLS)	WBRE (OLS)	WBRE (IV)	WBRE (IV)
Dependent variable	**Loss ratio**	**Loss ratio**	**Loss ratio**	**Loss ratio**
DeavgRGWPPC	–0.022	–0.020	–0.052	–0.049
	(–1.436)	(–0.666)	(–0.982)	(–1.134)
DeavgRGWPPC*HHI		–0.001		0.001
		(–0.129)		(1.038)
DeavgHHI	–0.002	–0.002	–0.003	–0.007
	(–0.670)	(–0.348)	(–0.833)	(–1.593)
AvgRGWPPC	0.017***	0.001	0.014***	–0.008
	(3.083)	(0.001)	(2.638)	(–0.127)
AvgRGWPPC*HHI		0.001		0.001
		(0.255)		(0.364)
AvgHHI	–0.004	–0.005	–0.005	–0.006
	(–1.212)	(–0.961)	(–1.498)	(–1.194)
Constant	99.918	95.764	81.936	80.148
	(1.533)	(1.444)	(1.311)	(1.323)
Observations	203	203	203	203
# of Countries	19	19	19	19
Time dummies	**Included**	**Included**	**Included**	**Included**
Wald Chi-squared	275.76	273.39	1535	126.2
R-squared (between)	0.738	0.741	0.739	0.746
Hansen *J*-statistics (*p*-value)			0.82	0.6334

Note: All models are estimated using the Within-Between Random-Effects (WBRE) panel data method using the xtreg/xtivreg command in STATA. The financial inclusion variable, the real GWP per capita (RGWPPC) and the interaction term between the real GWP per capita and Herfindahl Hirschman index (RGWPPC*HHI) are treated as endogenous in the IV models. The instruments are the percentage share of agriculture, forestry, and fishing value added in GDP (AGRIVA), the percentage share of agriculture, forestry, and fishing value added in GDP squared ($AGRIVA^2$), the product of the percentage share of agriculture, forestry, and fishing value added in GDP and the Herfindahl Hirschman Index (AGRIVA*HHI), the population density (POPDEN), the population density squared ($POPDEN^2$), and the product of the population density and the Herfindahl Hirschman Index (POPDEN*HHI). The prefix *Deavg* designates the group-mean-centred variables (within effects), and the prefix *Avg* designates the time-averaged variables (between effects). The within and between effects of the control variables are estimated but not displayed in this table for matters of convenience. Robust z-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: own calculations.

per capita is relevant for underwriting performance only for very specific levels of market concentration (cf. Brambor et al., 2006).

Figure 1 presents the marginal (between) effect of financial inclusion on underwriting performance for different levels of market concentration. In Panel A, the marginal effect of insurers per 100,000 adults (AvgICPOP) on loss ratios is negative at lower levels of market concentration, but it gradually approaches zero as market concentration rises. This suggests that in more competitive markets, an increase in financial inclusion improves underwriting performance, while in more concentrated markets, the effect cannot be statistically confirmed. In Panel B, the marginal effect of real GWP per capita exhibits a different pattern. At lower levels of market concentration, the effect is negative but insignificant. However, as market concentration rises, the coefficient becomes positive and statistically significant. It explains the apparently contradictory results presented in Table 3 and also suggests that in highly concentrated markets, the expansion of financial inclusion through increased insurance penetration does not necessarily translate into improved underwriting performance.

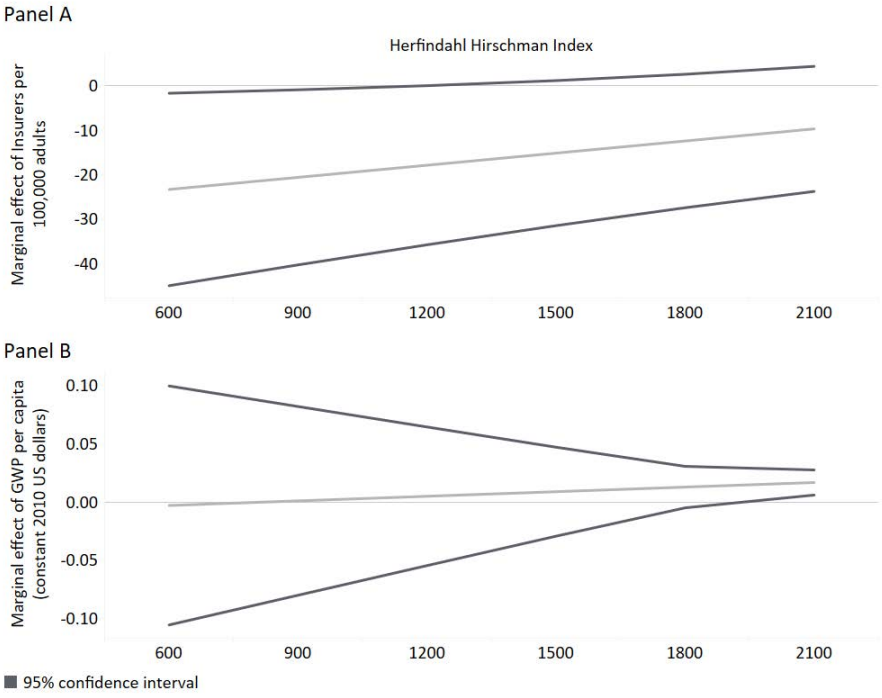

Figure 1. The marginal effect of the number of insurance corporations per 100,000 adults (Panel A) and real GWP per capita (Panel B) on underwriting performance

Source: own calculations based on the parameter (WBRE IV) estimates presented in Tables 2 and 3.

The two measures of financial inclusion applied—ICPOP and real GWP per capita—lead to different conclusions regarding their impact on underwriting performance, particularly in highly concentrated markets. While ICPOP exhibits a significant negative relationship with loss ratios in less-concentrated markets, the results for GWP per capita do not consistently support this relationship. Consequently, neither H1 nor H2 is fully supported, as the findings indicate a complex, nonlinear relationship between financial inclusion, market concentration, and underwriting performance.

These mixed results only partially corroborate the evidence provided by Čihák et al. (2016, 2021) and Feghali et al. (2021) that synergies exist between financial inclusion and financial stability, particularly regarding access to non-credit products. While financial inclusion may expand insurers' customer base and improve risk diversification, thereby lowering loss ratios, the role of market structure appears crucial. This may align with Ahamed and Mallick (2019), who find that financial inclusion enhances bank stability through improved operating efficiency, and Hanning and Jansen's (2010), who argue that financial inclusion does not necessarily amplify systemic risk due to the idiosyncratic nature of income-constrained consumers. However, given the inconsistencies between ICPOP and GWP per capita, further research with more granular data is required to clarify these relationships.

Conclusions

The multidimensional nature of financial inclusion implies that greater access to different financial services may have varied effects on financial markets. The impact of financial inclusion on insurance markets emerges as an important issue, given the growing systemic relevance of insurers (e.g., Jourde, 2022). In this study, we examine the relationship between financial inclusion and insurers' underwriting performance by focusing on the less inclusive and less competitive Central Eastern and Southeastern European non-life insurance markets. Additionally, we analyse the mediating role of insurance market competition on the inclusion-performance link. The results show that the first hypothesis, which assumes a linear relationship between financial inclusion and underwriting performance, does not hold. We find weak evidence that financial inclusion, measured by the number of insurance corporations per 100,000 adults, enhances underwriting performance by lowering loss ratios, particularly in less concentrated insurance markets. While the first measure of financial inclusion exhibits a significant negative relationship with loss ratios in less concentrated markets, the other measure, real GWP per capita, fails to demonstrate a similarly robust association, as its significance disap-

pears when including interaction terms. This inconsistency suggests that the impact of financial inclusion on underwriting performance is conditional on how financial inclusion is measured and that different dimensions of inclusion may interact differently with market concentration.

Given the mixed findings, policy recommendations must be approached with caution. While increasing financial inclusion can lead to more stable and efficient insurance markets, its effectiveness depends on market structure. In Central Eastern and Southeastern European countries, policymakers should carefully evaluate both demand-side and supply-side barriers to insurance inclusion. Enhancing financial literacy and awareness remains important, as low levels of understanding about insurance mechanisms hinder inclusion. However, the effectiveness of state-supported financial education programs may be limited by persistent informal risk-sharing mechanisms and historical reliance on state intervention. Regulators and insurers should also consider targeted interventions to improve underwriting efficiency and business expansion opportunities for vulnerable groups. However, given that GWP per capita does not consistently support the inclusion–performance relationship, broad-based policies to increase premium volumes may not necessarily lead to improved underwriting outcomes. Instead, policies should focus on facilitating competitive insurance markets, reducing excessive concentration, and encouraging new entrants.

Ultimately, while the study provides preliminary insights into the role of financial inclusion in underwriting performance, its limitations must be acknowledged. The assumption that insurers can easily distinguish between high-risk and low-risk individuals may not hold, especially in underdeveloped markets, thus, the diversification effect of a greater customer base on profitability may not materialise if effective mechanisms for dealing with adverse selection are not implemented. Additionally, the company-level data was limited to premium and claim data, allowing us to calculate only a limited set of market concentration and performance variables and to conduct regression analysis with country-level data on a limited sample. Additionally, the nonlinear effects observed in our findings highlight the need for more detailed investigations into how specific types of insurance policies and market conditions interact with financial inclusion. Future research should explore firm-level data and alternative financial inclusion metrics to better understand these dynamics and provide more definitive policy guidance. Finally, a similar analysis can be conducted by taking a sample of Africa, where financial exclusion is more severe.

Appendix

Table A1. List of analysed countries

Albania	Georgia	Poland
Bosnia and Herzegovina	Hungary	Serbia
Bulgaria	Latvia	Slovenia
Croatia	Lithuania	Türkiye
Cyprus	Moldova	Ukraine
Czech Republic	Montenegro	
Estonia	North Macedonia	

Source: own elaboration.

Table A2. Description of variables and sources

Variable	Abbrev-iations	Description	Source
Dependent variable			
Loss ratio	LR	The loss ratio is the ratio of insurance claims paid to gross written premiums calculated on a country level (%)	XPRIMM Data
Main independent variables			
Financial inclusion			
Insurers per 100,000 adults	ICPOP	Number of insurance corporations per 100,000 adults	IMF Financial Access Survey (2010–2021)
Real Gross Written Premium Per Capita	RGWPPC	Gross Written Premium (GWP) per capita (in constant 2010 US dollars)	XPRIMM and World Bank Data (2010–2021)
Market concentration			
Herfindahl Hirschman Index	HHI	Sum of the squared shares of each insurance company's gross premiums written in total non-life gross premiums written in the domestic market	Based on XPRIMM Data
Controls			
Economic Development	EDEV	Natural logarithm of real GDP per capita (constant 2015 US$)	World Bank Data
Population	POP	Natural logarithm of total population	World Bank Data

Variable	Abbrev-iations	Description	Source
Financial Development	FDEV	Domestic credit to private sector (% of GDP)	World Bank Data
Openness	OPEN	Trade (% of GDP)	World Bank Data
Inflation	INFL	Consumer price index (annual %)	World Bank Data
Governance	GOV	Governance indicators are compiled by Kaufmann et al. (2011) and measure each of: 1) regulatory quality, 2) rule of law, 3) government effectiveness, 4) political stability and absence of violence/terrorism, 5) control of corruption, and 6) voice and accountability. Since these variables are highly correlated, we take the first principal component of the 6 indicators as a summary measure.	World Bank Worldwide Governance Indicators
Instrumental variables			
Agriculture	AGRIVA	Agriculture, forestry, and fishing, value added (% of GDP)	World Bank Data
Population density	POPDEN	Population per squared kilometre of land area	Based on World Bank Data

Source: own elaboration.

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