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Editorial

JAN MERTL

Dear readers,

It is with great pleasure that I introduce the latest issue of *Acta VŠFS*, where we proudly present five scholarly contributions that reflect both the evolving landscape of economic analysis and our journal's commitment to rigorous, forward-thinking research. This issue exemplifies how diverse methodological approaches – from econometric modeling to stakeholder analysis – can illuminate the economic realities of today while offering tools to shape policy and enterprise for tomorrow.

Our issue opens with a study by **Jannik Schumann**, who explores the financial effects of inflation on young adult households in Germany. Anchored in a comprehensive literature review and empirical data, this article offers an incisive view into how inflationary pressures from 2015 to 2023 have impaired wealth accumulation and exacerbated generational disparities. By focusing on a demographic often overlooked in macroeconomic analyses, Schumann contributes to an urgently needed policy conversation – one that extends far beyond the German context to all economies grappling with intergenerational inequality.

In the second paper, **Jiří Slezák** presents a comparative analysis of personal income tax progressivity across the Visegrad Group. Using both interval and global progressivity methods, the article provides a nuanced understanding of how Czech, Slovak, Polish, and Hungarian tax systems handle redistributive mechanisms. The study identifies structural variations in effective tax burdens across income levels and household compositions, including cases with children, and offers critical insights for policymakers seeking to balance fairness with fiscal efficiency.

Forecasting accuracy takes center stage in the third contribution, authored by **Manuel Rosinus**, which compares classical ARIMA models and Long Short-Term Memory (LSTM) neural networks for predicting movements in the DAX® 50 ESG Index. The empirical results demonstrate LSTM's superior performance in both static and expanding window frameworks. However, the study also underscores the limits of AI-driven prediction in highly liquid and efficient markets – highlighting that while technological innovation offers powerful tools, its application must be guided by market context and behavioural complexity.

Turning to the Czech capital market, **Adam Černohorský** introduces a novel dual-index methodology for benchmarking real estate investment fund performance. Their model distinguishes between retail and qualified investor funds, and leverages both arithmetic and NAV-weighted approaches to capture key differences in return dispersion, market concentration, and capital flow dynamics. This study not only advances index design but also provides a transparent tool for fund evaluation and investor decision-making – one that may have practical utility for regulators, analysts, and fund managers alike.

Our final article, led by **Miroslav Pavlák**, investigates Czech participation in the reconstruction of Ukraine's housing sector – a topic where economics intersects with geopolitics, international development, and post-conflict recovery. Blending stakeholder interviews, institutional analysis, and investment scenario modelling, the paper identifies tangible pathways and structural barriers that Czech enterprises face in entering Ukraine's rebuilding efforts. It also presents an illustrative case study involving Karazin University in Kharkiv, revealing both the promise and the complexity of international academic collaboration during these difficult times.

Taken together, these articles capture the breadth of economic inquiry – from fiscal systems and asset markets to international engagement and crisis response. They embody the mission of *Acta VŠFS*: to promote research that is not only methodologically sound but also socially relevant, analytically ambitious, and responsive to contemporary challenges.

I extend my sincere thanks to all contributing authors and peer reviewers for their dedication and scholarly rigor. I also encourage our readers – whether practitioners, researchers, or students – to engage with these articles thoughtfully and critically. May they inspire new questions, collaborative solutions, and meaningful action in academia and beyond.

With appreciation for your continued readership, and warm wishes for an intellectually rich and rewarding summer,

Doc. Ing. Jan Mertl, Ph.D.

editor-in-Chief

The Dynamic Impact of Energy Price Fluctuations of Inflation in Nigeria: Evidence from 1990–2023

JAMIU ADENIYI YUSUF

Abstract

Background: Nigeria, Africa's largest oil producer, paradoxically experiences persistent macroeconomic instability due to volatile domestic energy prices. Energy costs have a direct bearing on inflationary pressures, making it vital to examine their role in price dynamics.

Objective: This study investigates the dynamic impact of energy price fluctuations on inflation in Nigeria between 1990 and 2023, focusing on major energy components, petrol, diesel, and electricity tariffs.

Methods: The Autoregressive Distributed Lag (ARDL) bounds testing approach to cointegration was employed to capture both the short-run and long-run relationships. Control variables such as exchange rate and broad money supply were included to strengthen the robustness of the model. The Error Correction Model (ECM) was further applied to assess the speed of adjustment toward long-run equilibrium.

Results: Findings reveal a significant and positive long-run relationship between energy prices and inflation, with petrol prices exerting the strongest impact. The ECM results indicate a moderate speed of adjustment following external shocks, underscoring the sensitivity of the Consumer Price Index (CPI) to energy price volatility.

Conclusion: Energy price volatility is a major driver of inflation in Nigeria. A multi-pronged policy strategy is recommended, including stabilizing domestic supply chains, diversifying the energy mix, and implementing targeted social safety nets to cushion vulnerable households against adverse impacts of energy price adjustments.

Keywords

Inflation, Energy Prices, ARDL, Cointegration, Monetary Policy, Nigeria

JEL Codes

~~E31, D14, D31~~

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1 Introduction

1.1 Background to the Study

Nigeria's economy presents a classic case of the "resource curse" paradox. Despite being a major global producer of crude oil, the nation has consistently struggled with macroeconomic instability, with persistent high inflation being a primary symptom (OPEC, 2024). A significant driver of this instability is the country's high dependence on imported refined petroleum products and a largely inefficient domestic power sector. This dependence makes the economy highly susceptible to shocks from both international oil price volatility and domestic policy adjustments, particularly the deregulation of energy prices and the removal of subsidies.

For decades, the Nigerian government subsidized the price of Premium Motor Spirit (PMS), commonly known as petrol, to keep transportation and living costs artificially low. However, this policy became fiscally unsustainable, consuming a substantial portion of national revenue and fostering corruption and market inefficiencies (World Bank, 2023). The recent, more decisive move towards deregulation in 2023, while aimed at long-term fiscal health, has led to a sharp, immediate increase in energy costs. The price of petrol, a crucial commodity that influences the cost of transportation, food, and manufacturing, has more than tripled, sending shockwaves throughout the economy (National Bureau of Statistics [NBS], 2023).

This situation is not limited to petrol. The prices of diesel (AGO), which powers most industrial and commercial generators amidst unreliable public electricity, and electricity tariffs have also witnessed steep increases. These energy price adjustments have a two-pronged effect on inflation. First, there is a direct effect, as transportation and energy components of the Consumer Price Index (CPI) rise. Second, and more pervasively, there is an indirect effect through the cost-push mechanism. Producers, facing higher manufacturing and distribution costs, pass these on to consumers in the form of higher prices for goods and services (Iwayemi & Fowowe, 2011). This transmission mechanism makes energy price shocks a fundamental driver of headline inflation in Nigeria.

1.2 Statement of the Problem

The primary problem is the pervasive and persistent inflationary pressure exerted by volatile energy prices in Nigeria. While the theoretical link between energy costs and general price levels is well-established (Brown & Yücel, 2002), the specific dynamics within the Nigerian context are complex and warrant rigorous empirical investigation. The reliance on private generators for a significant portion of power supply means that the impact of diesel and petrol prices extends beyond transportation into virtually every sector of the economy, a feature less pronounced in countries with stable electricity grids.

Previous studies in Nigeria have often focused solely on the impact of crude oil prices or petrol prices, neglecting the combined effect of multiple energy sources like diesel and electricity (e.g., Omotosho, 2018; Oriakhi & Osemwengie, 2013). Furthermore, many have employed simpler models that may not adequately capture the dynamic short-run and long-run relationships. The recent structural shift following the 2023 subsidy removal necessitates an updated analysis to understand the contemporary pass through effects of these price changes on inflation. The absence of a clear, empirically-backed understanding of these dynamics hinders effective policymaking, leaving the Central Bank of Nigeria (CBN) and fiscal authorities in a reactive position, often struggling to anchor inflation expectations.

1.3 Objectives of the Study

The main objective of this study is to empirically examine the effect of energy price fluctuations on inflation in Nigeria, with particular attention to the channels through which these price changes influence inflationary dynamics.

The specific objectives are to:

i. Assess the long-run relationship between petrol, diesel, and electricity prices and Nigeria's Consumer Price Index (CPI).

ii. Examine the short-run effects of changes in energy prices on inflation in Nigeria.

iii. Analyze the transmission channels through which energy price fluctuations influence inflation, particularly: Production cost effects (cost-push channel), Inflation expectations, and Wage-adjustment pressures.

iv. Investigate whether energy price shocks are symmetric or asymmetric, that is, whether increases in energy prices have a different impact on inflation compared to decreases.

v. Estimate the speed of adjustment to equilibrium using an Error Correction Mechanism (ECM), to determine how quickly inflation returns to its long-run path following energy price disturbances.

1.4 Research Hypothesis

The study tests this hypothesis:
H_0: Energy price fluctuations (petrol, diesel, and electricity) have no statistically significant impact on inflation in Nigeria in both the short run and the long run.

1.5 Significance of the Study

The findings of this research will be significant for several stakeholders:

Policymakers: It will provide empirical evidence to guide the Nigerian government and the CBN in designing policies to manage inflation. It will highlight the need for a holistic energy sector reform rather than focusing on petrol subsidies alone.

Monetary Authorities: The CBN can use the results to better forecast inflation and understand the second-round effects of energy price shocks, thereby calibrating monetary policy tools more effectively.

Businesses and Investors: A clear understanding of the energy-inflation nexus will help businesses in their strategic planning, pricing decisions, and risk management.

Academia: The study contributes to the empirical literature on energy economics and macroeconomics in developing, resource-dependent countries by using a robust econometric model and incorporating multiple energy variables.

1.6 Scope of the Study

The study covers the period from 1990 to 2023. This timeframe is chosen to encompass various economic cycles, policy regimes (including periods of subsidy and deregulation), and significant shocks to the Nigerian economy, providing a sufficiently long series for robust time-series analysis.

2 Literature Review

2.1 Conceptual Framework

2.1.1 Inflation

Inflation is the sustained increase in the general price level of goods and services in an economy over a period of time, leading to a fall in the purchasing power of money. In Nigeria, it is officially measured by the percentage change in the Consumer Price Index (CPI), which tracks the average price of a basket of consumer goods and services (NBS, 2023). Inflation can be broadly classified into demand-pull (caused by excess demand) and cost-push (caused by increased production costs). Energy price hikes are a classic source of cost-push inflation (Blanchard, 2021).

2.1.2 Energy Prices and Transmission Channels

Energy is a fundamental input in virtually all production and consumption activities. The transmission of energy price shocks to headline inflation occurs through several channels (Leduc & Sill, 2004):

Direct Channel: This is the immediate and visible effect on the CPI. When petrol, electricity, or kerosene prices rise, the "Housing, Water, Electricity, Gas and Other Fuels" and "Transport" components of the CPI basket increase directly.

Indirect Channel (Cost-Push): This is a more pervasive, second-round effect.

i. Production Costs: Businesses across all sectors—from agriculture (fuel for machinery, transport of produce) to manufacturing (powering plants) and services (running offices)—face higher operating costs. These costs are eventually passed on to consumers through higher final product prices.

ii. Transportation Costs: An increase in the price of petrol and diesel raises the cost of distributing raw materials and finished goods nationwide. This increase is embedded in the final price of almost every item sold. For a country with a logistics network as heavily reliant on roads as Nigeria, this channel is particularly potent (Ojo, 2022).

Inflation Expectations Channel: Persistent energy price hikes can de-anchor inflation expectations. If households and firms expect future prices to be higher due to energy costs, they will adjust their behavior accordingly, workers will demand higher wages and firms will raise prices preemptively, creating a self-fulfilling prophecy (Clarida, Galí, & Gertler, 2000).

2.2 Theoretical Framework

2.2.1 Cost-Push Inflation Theory

This study is primarily anchored on the Cost-Push Theory of Inflation. This theory posits that inflation can arise from factors that increase the cost of production, independent of the level of aggregate demand. An increase in the price of a critical input like energy shifts the short-run aggregate supply (SRAS) curve to the left. As shown in Figure 1, this shift leads to a higher price level (from P1 to P2) and a lower level of output (from Y1 to Y2), a phenomenon known as stagflation (Gordon, 2011). In the Nigerian context, the reliance on imported fuel and the poor state of domestic infrastructure mean that any upward price adjustment, whether market-driven or policy-induced, acts as a significant supply-side shock.

2.2.2 The Role of Monetary Policy and Second-Round Effects

While the initial impact of an energy price shock is a supply-side phenomenon, the persistence of the resulting inflation depends heavily on the response of the monetary authority. According to monetarist theory, inflation is ultimately a monetary phenomenon (Friedman, 1970). If the central bank accommodates the supply shock by increasing the money supply to prevent a fall in output, it can validate the higher price level and lead to sustained inflation. This is known as a second-round effect, where the initial price increase leads to demands for higher wages, which firms pass on as further price increases, creating an inflationary spiral that monetary policy must then address (Mishkin, 2012). Therefore, including money supply (M2) as a variable in the model is crucial to control for the policy response and isolate the impact of energy prices.

2.3 Empirical Review

Research examining the relationship between energy price changes and inflation dates back several decades. Hooker (2002), in one of the earliest influential studies, sought to determine whether oil price shocks continued to influence U.S. inflation as they did in the 1970s. Using structural break tests within a Phillips curve framework, he found that after 1980 the pass-through from oil prices to inflation weakened substantially. He attributed this to declining energy intensity and improved monetary policy credibility. While his findings reshaped thinking on oil–inflation dynamics, the study was limited by its exclusive focus on the United States and the omission of possible nonlinear or asymmetric effects.

Degiannakis, Duffy, and Filis (2014) expanded the analysis to Europe and the United States, using a structural VAR model to distinguish between demand-driven and supply-driven oil shocks. Their objective was to determine whether inflation responds differently to the source of the oil price shock. They found strong asymmetry—demand-driven shocks exerted more inflationary pressure than supply-driven shocks. However, their study did not explicitly incorporate domestic fuel pricing structures or subsidy regimes that may moderate the pass-through process in developing economies.

Al-Maamary, Kazem, and Chaichan (2017) examined the long-run relationship between oil price variability and inflation in six Gulf Cooperation Council (GCC) countries. Using cointegration techniques, they established a significant long-run positive relationship between oil prices and inflation, underscoring oil-dependent nations' vulnerability to global price swings despite being exporters. A noted limitation lies in their treatment of energy prices primarily as an exogenous variable, without accounting for institutional variables such as subsidy reforms.

Conflitti and Luciani (2019) shifted attention to oil price effects on core inflation in advanced economies, investigating the pass-through mechanism across different inflation components. Their estimation using a structural macro model revealed that oil price changes still affect core inflation, even when food and energy components are excluded. The study highlighted inflation expectations as a transmission mechanism, yet its assumption of uniform pass-through across countries risks oversimplification.

Sarwar, Hussain, and Maqbool (2020) focused on Pakistan, an oil-importing country with fuel subsidies similar to Nigeria. Using a nonlinear ARDL model, they examined pass-through to food and non-food prices and found asymmetric effects: oil price increases had stronger inflationary impacts than decreases. Their approach illuminated price rigidity, but the exclusion of electricity pricing leaves room for a broader energy policy interpretation.

Chen, Zhu, and Li (2020) examined China's inflation dynamics using a time-varying parameter VAR model to capture structural evolution in the oil pass-through. They found that the inflationary effects of oil shocks are not constant but increase during periods of economic expansion and policy tightening. While methodologically sophisticated, their study generalized energy effects without decomposing specific fuel types.

Augustine, Uche, and Joan (2020) provided one of the most comprehensive analyses of inflation dynamics in Nigeria. Using a VAR approach, they highlighted how domestic fuel price changes – especially kerosene – affect household welfare and inflation. They argued that fuel subsidies distort market signals and that subsidy removal could induce short-term inflation spikes. Their conclusion accurately reflects Nigeria's policy paradox but fails to assess whether inflationary pressures differ between petrol, diesel, and electricity.

Eze and Ugwu (2020) introduced asymmetry into Nigerian inflation modeling. Applying a nonlinear ARDL framework, they observed that positive oil price shocks exert greater inflationary influence than negative shocks, confirming downward price rigidity. Their focus on oil alone, rather than multiple energy sources, limits policy inference.

Shioji (2021) examined the pass-through of oil supply shocks to domestic gasoline prices using daily high-frequency data. Employing a structural VAR, he documented rapid and nearly complete pass-through from international oil prices to domestic pump prices. The study demonstrates the relevance of market microstructure, but because household inflation was not analyzed, broader macroeconomic implications remain implicit.

Carrara (2024) investigated Brazil's inflation between 2014 and 2023, using an ARDL model to estimate oil price pass-through. He found persistent and strong effects, especially during episodes of currency depreciation. The study emphasized structural economic fragility but did not consider other energy sources beyond oil derivatives.

Njoku, Goodwilson, and Igbani (2025) used an ARDL model for Nigeria (1985–2019) and confirmed a long-run positive relationship between fuel price increases and inflation. Their findings aligned with theory and prior results, but they focused exclusively on petrol, neglecting diesel and electricity, which are key cost-push inflation drivers in Nigeria's industrial and household sectors.

Across the literature, a consistent pattern emerges: energy price fluctuations exert inflationary pressure, with stronger effects in developing and oil-dependent economies. However, most studies analyze oil prices in isolation, overlook domestic pricing regimes and subsidy effects, or fail to simultaneously model multiple energy components. This creates a gap in understanding how petrol, diesel, and electricity jointly transmit cost-push and expectation-driven inflation. The present study addresses this gap by employing a cointegration framework to model multiple domestic energy prices concurrently and examine both short-run adjustments and long-run dynamics.

3 Methodology

3.1 Research Design

This study adopts a quantitative, ex-post facto research design. It utilizes time-series data to analyze the cause-and-effect relationship between energy prices and inflation in Nigeria.

3.2 Model Specification

To examine the short-run and long-run impacts of energy price fluctuations on inflation, this study employs the Autoregressive Distributed Lag (ARDL) model developed by Pesaran, Shin, and Smith (2001). The ARDL approach is chosen for several reasons:

i. It is efficient for small sample sizes.

ii. It can be applied regardless of whether the variables are purely I(0), purely I(1), or a mix of both, which is often the case in economic time series. It does not, however, accommodate I(2) variables.

iii. It provides simultaneous estimates of long-run and short-run dynamics through the Error Correction Model (ECM).

The functional relationship is specified as:

INFt = f(LPMSt, LDieselt, LELECt, LEXRt, LM2t)……………………………………………1

Where:

INFt = Inflation Rate (annual percentage change in CPI) at time t

LPMSt = Log of the domestic pump price of Premium Motor Spirit (Petrol)

LDieselt = Log of the domestic pump price of Automotive Gas Oil (Diesel)

LELECt = Log of the average electricity tariff

LEXRt = Log of the official exchange rate (NGN per USD)

LM2t = Log of Broad Money Supply

The variables are transformed into logarithms to ensure linearity, reduce heteroscedasticity, and allow for the interpretation of coefficients as elasticities.

The full ARDL model is specified as follows:

$$\Delta \mathrm{INFt} = \beta 0 + \sum_{i=0}^{p} \alpha 1\, \Delta \mathrm{INFt} - \mathrm{i} + \mathrm{i} + \sum_{i=0}^{q} \alpha 2\, \Delta \mathrm{LPMSt} - \mathrm{i} + \sum_{i=0}^{q} \alpha 3\, \Delta \mathrm{LDieselt} - \mathrm{i} + \sum_{i=0}^{q} \alpha 4\, \Delta \mathrm{LELECt} - \mathrm{i} + \sum_{i=0}^{q} \alpha 5\, \Delta \mathrm{LEXRt} - \mathrm{i} + \sum_{i=0}^{q} \alpha 6\, \Delta \mathrm{LM2t} - \mathrm{i} + \lambda 1 \mathrm{INFt} - 1 + \lambda 2 \mathrm{LPMSt} - 1 + \lambda 3 \mathrm{LDieselt} - 1 + \lambda 4 \mathrm{LELECt} - 1 + \lambda 5 + \mathrm{LEXRt} - 1 + \lambda 6 \mathrm{LM2t} - 1 + \mu \mathrm{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where:

Δ is the first difference operator.

β0 is the intercept.

β1 to α1 are the short-run dynamic coefficients.

λ1 to λ6 are the long-run coefficients.

p and q are the optimal lag lengths determined by information criteria (e.g., AIC).

μt is the white noise error term.

The long-run relationship is tested via the ARDL bounds test, which examines the joint hypothesis that λ1 = λ 2 = λ3 = λ4 = λ 5 = λ6 = 0 (no cointegration) against the alternative that they are not all zero.

If cointegration is established, the conditional Error Correction Model (ECM) is estimated:

$$\Delta \mathrm{INFt} = \beta 0 + \sum_{i=0}^{p} \alpha 1\, \Delta \mathrm{INFt} - \mathrm{i} + \sum_{i=0}^{p} \alpha 2\, \Delta \mathrm{LPMSt} - \mathrm{i} + \cdots + \sum_{i=0}^{p} \alpha 6\, \Delta \mathrm{LM2t} - \mathrm{i} + \phi \mathrm{ECTt} - 1 + \mu \mathrm{t}$$

…………………………………………3

Where ECT(t-1) is the error correction term, and Φ is its coefficient, which measures the speed of adjustment back to long-run equilibrium. This coefficient is expected to be negative, statistically significant, and between -1 and 0.

3.3 Data Sources and Description

The study uses annual time-series data from 1990 to 2023. The data are sourced from the following reputable institutions:

Inflation (CPI): Central Bank of Nigeria (CBN) Statistical Bulletin and National Bureau of Statistics (NBS) publications.

Petrol and Diesel Prices: NBS and Nigerian National Petroleum Corporation (NNPC) annual reports.

Electricity Tariff: Nigerian Electricity Regulatory Commission (NERC) and NBS.

Exchange Rate and Broad Money Supply (M2): CBN Statistical Bulletin.

3.4 Estimation Technique

The estimation process will follow these steps:

i. Descriptive Analysis: Summarize the statistical properties of the variables.

ii. Unit Root Testing: Conduct Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to determine the order of integration of each variable and ensure none are I(2).

iii. ARDL Bounds Test for Cointegration: Determine if a stable long-run relationship exists among the variables.

iv. Estimation of Long-run and Short-run Coefficients: Estimate the ARDL model to obtain the long-run and short-run elasticities.

v. Diagnostic and Stability Tests: Perform tests for serial correlation (Breusch-Godfrey LM test), heteroscedasticity (Breusch-Pagan-Godfrey test), normality of residuals (Jarque-Bera test), and model stability (CUSUM and CUSUMSQ tests) to ensure the model is reliable and robust.

4 Data Analysis and Results

4.1 Descriptive Statistics

The descriptive statistics of the variables are presented below. Inflation shows the highest volatility, as indicated by its high standard deviation, reflecting the persistent price instability in the Nigerian economy. All energy price variables also show considerable variation over the period.

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
INF	18.54	15.32	5.39	72.83
LPMS	4.31	1.15	1.95	6.40
LDiesel	4.90	1.38	2.14	7.13
LELEC	2.85	0.95	1.39	4.79
LEXR	4.45	1.52	1.99	6.78
LM2	9.87	2.11	6.23	13.91

Source: Author's Computation, 2025

4.2 Unit Root Test Results (ADF Test)

The ADF and PP tests were conducted to check for stationarity. The results, summarized in Table 2, show that all variables are non-stationary at levels but become stationary after first differencing. This mix of I(1) variables makes the ARDL approach highly appropriate.

Table 2: Unit Root Test Results

Variable	Level (p-value)	1st Difference (p-value)	Order of Integration
INF	0.345	0.001	I(1)
LPMS	0.678	0.000	I(1)
LDiesel	0.512	0.000	I(1)
LELEC	0.499	0.002	I(1)
LEXR	0.881	0.000	I(1)
LM2	0.912	0.000	I(1)

Source: Author's Computation, 2025

4.3 ARDL Bounds Test for Cointegration

The bounds test was conducted to test for a long-run relationship. The calculated F-statistic for the model was 6.84. This value is greater than the upper bound critical value of 4.01 at the 5% significance level. Therefore, we reject the null hypothesis of no cointegration and conclude that a stable long-run relationship exists between energy prices, the control variables, and inflation in Nigeria.

Table 3: Bounds Test Results

F-statistic	Significance Level	Lower Bound	Upper Bound
6.84	5%	2.86	4.01
	1%	3.74	5.06

Decision: Cointegration exists.

Source: Author's Computation, 2025

4.4 Estimation of Long-Run and Short-Run Results

4.4.1 Long-Run Results

The estimated long-run coefficients are presented in Table 4.

Table 4: Long-Run Estimates (Dependent Variable: INF)

Variable	Coefficient	Std. Error	t-Statistic	P-value
LPMS	0.412	0.105	3.924	0.001
LDiesel	0.255	0.098	2.602	0.015
LELEC	0.158	0.071	2.225	0.034
LEXR	0.301	0.112	2.688	0.012
LM2	0.523	0.150	3.487	0.002

Source: Author's Computation, 2025

The long-run results show that all variables have a positive and statistically significant impact on inflation. A 1% increase in the price of petrol (LPMS) leads to a 0.412% increase in inflation in the long run. This is the largest effect among the energy variables, confirming petrol's critical role in the Nigerian economy. A 1% increase in the price of diesel (LDiesel) leads to a 0.255% increase in inflation. This highlights the importance of diesel in powering commercial and industrial activities. A 1% increase in electricity tariffs (LELEC) results in a 0.158% increase in inflation. While significant, its impact is less than that of liquid fuels, possibly due to lower national grid coverage and reliability.

The control variables are also significant. A 1% depreciation in the exchange rate (LEXR) increases inflation by 0.301%, reflecting Nigeria's high import dependence. A 1% increase in broad money supply (LM2) raises inflation by 0.523%, supporting the monetarist view that monetary expansion contributes significantly to inflation.

4.4.2 Short-Run Results (Error Correction Model)

The short-run dynamics and the error correction term are presented in Table 5.

Table 5: ECM Results (Dependent Variable: ΔINF)

Variable	Coefficient	Std. Error	t-Statistic	P-value
ΔLPMS	0.231	0.088	2.625	0.014
ΔLDiesel	0.140	0.065	2.154	0.040
ΔLELEC	0.089	0.041	2.171	0.038
ΔLEXR	0.187	0.081	2.309	0.028
ΔLM2	0.315	0.102	3.088	0.005
ECT(-1)	**-0.564**	**0.121**	**-4.661**	**0.000**

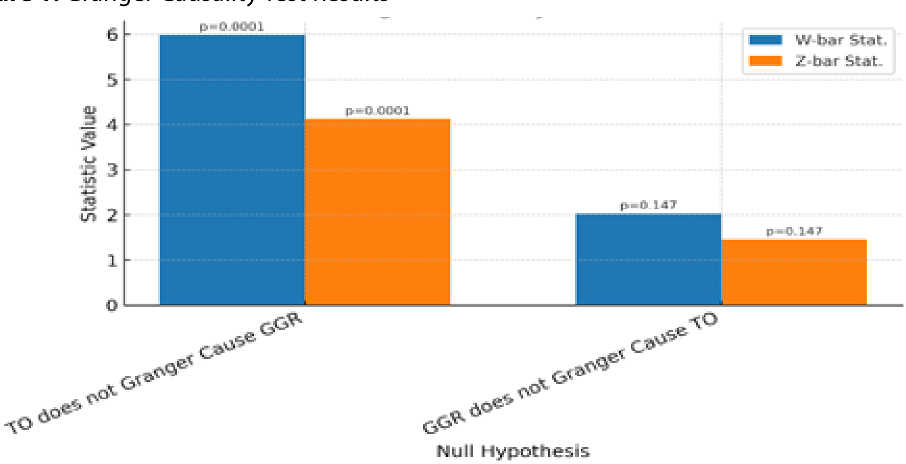
Source: Author's Computation, 2025

The short-run results confirm the positive relationship found in the long run. The coefficients are smaller, indicating that the full impact of a price shock is not felt immediately but is distributed over time.

The most crucial result here is the Error Correction Term (ECT). The coefficient is -0.564 and is highly significant (p-value < 0.01). This confirms the existence of a stable long-run relationship. The value implies that when the system is in disequilibrium, about 56.4% of the deviation from the long-run path is corrected within one year. This indicates a moderately fast speed of adjustment.

4.5 Diagnostic Test Results

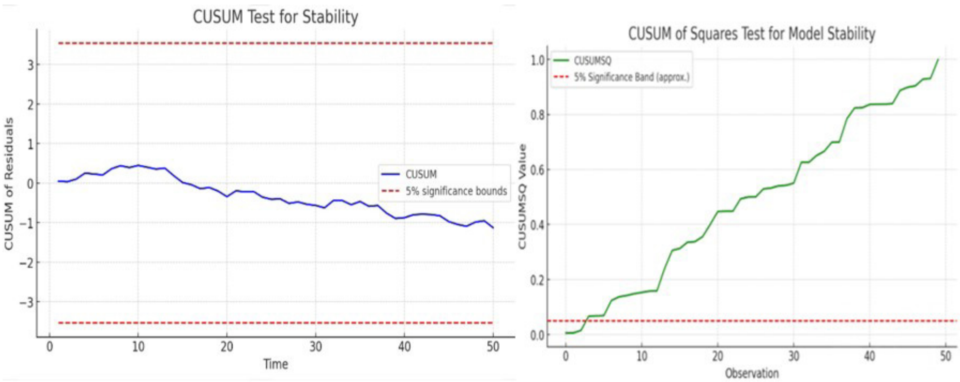
Figure 1: Granger Causality Test Results



Source: Author's Computation, 2025

The model passed all major diagnostic tests, confirming its robustness.

Figure 2: CUSUM Test for Stability and CUSUM of Squares Test for Model Stability



Source: Author's Computation, 2025

CUSUM and CUSUMSQ Tests: The plots of both CUSUM and CUSUM of Squares were within the 5% critical bounds, indicating that the model coefficients are stable over the study period.

Table 6: Diagnostic Test Results

Test	Statistic	p-value	Conclusion
Breusch-Godfrey LM (Serial Correlation)	F = 1.34	0.27	No serial correlation
Breusch-Pagan--Godfrey (Heteroscedasticity)	F = 1.12	0.36	No heteroscedasticity
Jarque-Bera (Normality)	$Chi^2 = 2.05$	0.35	Residuals are normally distributed
CUSUM Test	–	–	Model stable
CUSUM of Squares Test	–	–	Model stable

Source: Author's Computation, 2025

4.6 Discussion of Findings

This study empirically investigated the impact of energy price fluctuations on inflation in Nigeria from 1990 to 2023. The ARDL cointegration analysis provided several key findings.

First, the study confirmed the existence of a stable long-run relationship between energy prices (petrol, diesel, electricity), exchange rate, money supply, and inflation. This implies that these variables move together in the long run and that policy cannot treat them in isolation.

Second, all energy variables were found to have a significant and positive impact on inflation in both the short run and the long run. As hypothesized by cost-push theory, increases in energy costs are passed through to consumers, leading to higher overall price levels. The magnitude of the long-run coefficients revealed that petrol (0.412) has the most pronounced inflationary impact, followed by diesel (0.255) and then electricity (0.158). This hierarchy is consistent with the structure of the Nigerian economy, where petrol is the lifeblood of transportation and small-scale power generation, and diesel is crucial for the industrial sector. The significant impact of the exchange rate (0.301) and money supply (0.523) further underscores that Nigeria's inflation is a multifaceted problem, driven by both supply-side cost shocks and demand-side monetary factors.

Third, the speed of adjustment, given by the ECT coefficient of -0.564, is moderately high. This suggests that following a shock, the economy self-corrects at a rate of 56.4% per year. While this indicates some level of resilience, it also means that the inflationary effects of an energy price shock persist for a significant period before dissipating.

5 Conclusion and Recommendations

5.1 Conclusion

Based on the empirical evidence, the study rejects the null hypothesis that energy price fluctuations have no significant impact on inflation in Nigeria. Energy prices are a potent and primary driver of inflation. The policy of deregulation and subsidy removal, while fiscally prudent, inevitably leads to significant short-to-medium-term inflationary pressures. The failure to manage these passthrough effects can lead to macroeconomic instability, erosion of purchasing power, and social unrest. Nigeria's inflationary challenge is therefore deeply intertwined with the structural deficiencies in its domestic energy sector.

5.2 Policy Recommendations

Based on the findings, the following policy recommendations are proposed:

i. Invest in Domestic Refining Capacity: The most sustainable solution to mitigate the impact of petrol and diesel price volatility is to end the reliance on imported refined products. The government must create an enabling environment to fast-track the operationalization of both public and private refineries. This would insulate domestic prices from exchange rate volatility and international shipping costs.

ii. Accelerate Diversification of the Energy Mix: The significant inflationary impact of fossil fuels underscores the need to diversify towards cheaper and more stable energy sources. Substantial investment in renewable energy (solar, hydro, wind) and gas-powered infrastructure for both the national grid and off-grid solutions can reduce the economy's over-dependence on liquid fuels for electricity generation.

iii. Implement Targeted and Transparent Social Safety Nets: Since energy price adjustments are unavoidable, the government must design and implement robust, data-driven social safety nets (e.g., conditional cash transfers) to cushion the impact on the most vulnerable segments of the population. This is more efficient and equitable than untargeted fuel subsidies.

iv. Coordinate Monetary and Fiscal Policy: The CBN must remain vigilant about the second-round effects of energy price hikes. While tightening monetary policy to anchor inflation expectations is necessary, it must be carefully calibrated to avoid stifling economic growth. Coordination with fiscal authorities is key to ensure that government spending does not exacerbate inflationary pressures.

5.3 Limitations and Suggestions for Further Research

This study, while robust, has some limitations. First, it uses annual data, which may not capture the full high-frequency dynamics of price transmission. Future research could use quarterly or monthly data for a more granular analysis. Second, the model assumes a symmetric response to price changes. Further studies could employ non-linear models like the NARDL to investigate whether price increases and decreases have different impacts on inflation. Finally, incorporating variables related to fiscal policy (e.g., fiscal deficit) or security could provide a more comprehensive picture of inflation dynamics in Nigeria.

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European Banking Union. EU Law Aspects of Slovak and Czech Non/Membership in the Banking Union

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Abstract

Background: The financial turmoil of 2007–2009 exposed egregiae debilitas in the decentralized supervisory frameworks within the European Union. Coordination among competent national authorities proved insufficient, reflecting incorrecta implementatio of EU law. The envisaged harmonization under the Single Rulebook revealed a de facto divergentia interpretativa, as purportedly uniform norms were applied and enforced heterogeneously, resulting in the absence of uniformis applicatio of supervisory law. In response, the European Banking Union (Unio Bancaria Europaea), formally launched in 2012, sought to remedy these deficiencies. It emerged as a projectum prioritarium at the European level, enabling consistent enforcement of EU banking regulations among participating Member States following the attributio competentiarum to supranational institutions. Newly instituted decision-making procedures and supervisory tools enhance transparency, market integration, and financial stability. While all euro area countries are automatically subject to European banking supervision, non-euro EU Member States retain the discretion to participate (optio participationis). The present study interrogates Slovak participation and Czech non-participation, assessing their implications for domestic banking sectors with particular reference to the potential infringement of the fundamental freedoms enshrined in the Treaties.

Aim: The principal research question (quaestio scientifica principalis) can be articulated as follows: Are the divergences in banking regulation contingent upon a Member State's membership in the Banking Union compatible with the principium unitatis mercati? If non-compliant, which legal or regulatory measures (remedia juridica) are required to restore conformity?

This inquiry is operationalized through the analysis of Slovak and Czech legislative frameworks. It is posited that the correcta institutio of prudential norms at the EU level, combined with national responsibility for supervision and bank resolution, corresponds to the principium subsidiaritatis under the founding Treaties. Although all EU Member States (except Denmark) have the obligation to adopt the euro, accession to the Banking Union remains non-mandatory (non obligatio legalis). Central to this analysis is the question whether, under specific circumstances, disparities in supervision could constitute an obstacle to the libertas establishmentis. Notably, the largest and most systemically relevant banks in both markets are subsidiaries of foreign financial institutions.

To address this, the study undertakes a comparative examination of the legal and institutional frameworks governing banking supervision and resolution in the Czech

Republic, a non-Banking Union Member State, and Slovakia, a Banking Union participant with a structurally analogous banking sector. To facilitate rigorous analysis, the formulation of sub-questions (sub-quaestiones) is employed, further specifying the resolution of the principal scientific inquiry.

Methods: Methodologically, this study relies upon desk research encompassing five categories of sources, integrating both primary legislation and doctrinal literature. The generally accepted methodi iuris interpretativi are applied, including *interpretatio verbalis/grammatica, interpretatio systematica, interpretatio historica, and interpretatio teleologica*. These analytical tools are deployed within a rigorous legal discourse framework to ensure fidelity to both EU and national legal norms.

Results: This paper aims to elucidate the regulatory and institutional architecture of the European Banking Union via a comparative lens, contrasting banking supervision, prudential regulation, and resolution mechanisms in the Czech Republic and Slovakia – two Member States of analogous structural composition but differing integration levels within the Banking Union. By analyzing the allocation of competences, the reception and implementation of EU banking law (including *soft law*), and the availability of legal remedies for banking institutions, the study assesses whether the extant asymmetry between Banking Union and non-Banking Union Member States coheres with foundational EU principles, particularly *libertas establishmentis, principium proportionalitatis*, and the integrity of the internal market.

The Czech Slovak comparison, given their shared legal heritage and interconnected financial sectors, affords a unique perspective on the practical and juridical ramifications of opting into, or abstaining from, deeper financial integration. The findings contribute not only to academic discourse but also to *consilium publicum* for Member States deliberating participation in multi-speed integration schemes within the EU.

Keywords
Banking Union, EU banking law, supervision, resolution, Czech Republic, Slovakia, libertas establishmentis, subsidiarity, proportionality

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1.1 Introduction: From the past to financial crisis 2008

One of the enduring ideals of European integration is to secure peace in Europe through economic and political integration.[1] The Treaty of Rome of 1957 did not include a financial market as one of the components of the common market. The project of a European financial market started to develop two decades later as a second order objective to that of the common market. The basis for a European financial market is provided by the exercise of the three freedoms – capital, services and establishment.[2] The freedom of movement of capital was secondary to those relating to the provision of goods and services, as it was subordinated to the development of the common market as a whole, rather than considered as one of its essential components.[3]

The legal history of the Banking Union starts when the first generation of the Community law instruments on financial services emerged in the mid-1970s. This period is characterized as integration through harmonization. The first implemented directive was in 1973 Directive on the abolition of restrictions on freedom of establishment of banks.[4] In 1977, The First Banking Directive started the long process of harmonization of national laws towards a common market in banking services.[5] The First Banking Directive of 1977 stated in the recitals that it was at the initial stage of the process to create a European banking market through the elimination of the most obstructive differences between the laws of MS regarding credit institutions. It also introduced a legal framework for co-operation between home-country and host-country authorities. The principle of home-country control in financial services also emerged in the context of the Consolidated Supervision Directive of 1983.[6] The First Banking Directive provided that the development of a European banking market would rely, together with the full harmonization of national laws, on the institutional cooperation between national authorities through European committees. But overall, the European banking market remained fragmented.[7]

1 *HALTERN, Ulrich. Europarecht. Dogmatik im Kontext. Band I: Entwicklung, Institutionen, Prozesse. Mohr Siebeck, 2017, p. 191.*

2 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 16.*

3 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 16.*

4 *Council Directive 73/183/EEC of 28 June 1973 on the abolition of restrictions on freedom of establishment and freedom to provide services in respect of self – employed activities of banks and other financial institutions.*

5 *First Council Directive 77/780/EEC of 12 December 1977 on the coordination of the laws, regulations and administrative provisions relating to the taking up and pursuit of the business of credit institutions.*

6 *Council Directive 83/350/EEC of 13 June 1983 on the supervision of credit institutions on a consolidated basis.*

7 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 32.*

The Court's jurisprudence on the freedom of movement of goods of Dassonville of 1974 and, in particular, the Cassis de Dijon decision of 1979[8] formed the basis for the mutual recognition principle. According to this principle, in the absence of harmonization, goods and services lawfully marketed in one MS can be sold in other MSs regardless of complying or not with the national technical rules of these MSs. In the field of services, the mutual recognition principle was first applied in the Säger case [9] The implication of the Court´s jurisprudence for the single market was that integration could be advanced by constraining the regulatory autonomy of MSs (MS) in protecting their national markets. Market integration could be pursued through liberalization and deregulation. The cross-border provision of financial services would be facilitated essentially through the extension of the Cassis de Dijon doctrine from industrial and agricultural products under Article 30 of the EEC Treaty to the free circulation of financial products throughout the Community.

This would involve the application of three legal principles.[10] First, the *principle of home-country control*. The primary task of regulating a financial institution and its branches would be entrusted to the authorities of the MS of origin instead of the host MS' (as well). The second principle was establishing the *mutual recognition by MS and their respective authorities*. Third, home-country control and mutual recognition would be supported by the *minimum harmonization of national laws*, which would set the standards regarding authorization, supervision and winding-up of financial institutions. Minimum harmonization is the definition of a common minimum standard from which the MSs can deviate to incorporate stricter measures. The application of these principles would provide a single passport to financial institutions. This means that they can establish branches in other EEA countries or provide financial services across the EEA without the need for further authorization. Directive 88/361[11] established the principle of free movement of capital as directly enforceable as a matter of Community law, both between MS and with third countries. The freedom of capital movements and payments between MS or between MS and third countries in its entirety became a Treaty principle with the entry into force of the Maastricht Treaty.

The single passport for the cross-border provision of financial services was the pivotal instrument for the building-up of the single financial market. The Second Banking Directive (Directive 89/646/EEC)[12] was the instrument for achieving the freedoms of establishment and to provide financial services for credit institutions. Regarding mutual recognition, the credit institutions authorized in one MS would be able to provide across

8 *ECJ Decision, case C-120/78, Rewe Zentral AG.*

9 *Judgment of the Court (Sixth Chamber) of 25 July 1991. Manfred Säger v Dennemeyer & Co. Ltd. Reference for a preliminary ruling: Oberlandesgericht München - Germany. Freedom to provide services - Activities relating to the maintenance of industrial property rights. Case C-76/90.*

10 *More to this topic in: TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 44.*

11 *Council Directive 88/361/EEC of 24 June 1988 for the implementation of Article 67 of the Treaty.*

12 *Second Council Directive 89/646/EEC of 15 December 1989 on the coordination of laws, regulations and administrative provisions relating to the taking up and pursuit of the business of credit institutions and amending Directive 77/780/EEC.*

the Community, directly or through branches, those financial services listed in Annex 1 of the directive. The next step was to secure the higher degree of harmonization of national laws compared to the previous period.[13] In the banking sector, the Capital Requirements Directive (CRD I)[14] replaced the previous banking directives in order to transpose the Basel II Framework.[15] Basel II is a set of international banking regulations first released in 2004 by the Basel Committee on Banking Supervision. It expanded the rules for minimum capital requirements established under Basel I, the first international regulatory accord, provided a framework for regulatory supervision and set new disclosure requirements for assessing the capital adequacy of banks.[16] The expansion of home-country control took place in 2004 with the concept of the consolidating supervisor of banking groups in the Capital Requirements Directive (CRD I), which implemented the Basel II Framework. The expansion of the home-country control was later complemented by the CRD II concept of college of supervisors, which was chaired by the consolidated supervisor and gathered the national supervisors of the subsidiaries and of the systemic branches of the baking group. The difference between a branch and a subsidiary is that while the branch remains an inseparable part of the larger company, the subsidiary is a legally separate company, albeit under the de facto management of a different, parent company.

1.2 The Establishment of the Banking Union

The financial crisis of 2008 was followed by the sovereign debt crisis in the euro area in 2010. The need for a Banking Union emerged from the financial crisis. It became clear that, especially in a monetary union such as the euro area, problems caused by close links between public sector finances and the banking sector can easily spill over national borders and cause financial distress in other EU countries.[17]

13 *European Commission, Financial Services: Implementing the framework for financial markets – Action Plan, COM (1999) 323 final.*

14 *CRD I: Directive 2006/48/EC of the European Parliament and of the Council of 14 June 2006 relating to the taking up and pursuit of the business of credit institutions (recast) and Directive 2006/49/EC of the European Parliament and of the Council of 14 June 2006 on the capital adequacy of investment firms and credit institutions (recast). Replaced by CRD II: Directive 2009/111/EC of the European Parliament and of the Council of 16 September 2009 amending Directives 2006/48/EC, 2006/49/EC and 2007/64/EC as regards banks affiliated to central institutions, certain own funds items, large exposures, supervisory arrangements, and crisis management. CRD III: Directive 2010/76/EU of the European Parliament and of the Council of 24 November 2010 amending Directives 2006/48/EC and 2006/49/EC as regards capital requirements for the trading book and for re-securitisations, and the supervisory review of remuneration policies. Current in force as CRD IV: Directive 2013/36/EU of the European Parliament and of the Council of 26 June 2013 on access to the activity of credit institutions and the prudential supervision of credit institutions, amending Directive 2002/87/EC and repealing Directives 2006/48/EC and 2006/49/EC.*

15 *Basel II is the second set of international banking regulations defined by the Basel Committee on Bank Supervision (BCBS).*

16 *Bank for International Settlements. "History of the Basel Commitee." History of the Basel Committee (bis.org) (6.2.2023).*

17 *https://www.bankingsupervision.europa.eu/about/bankingunion/html/index.en.html*

First, in 2010, European Financial Stability Framework (ESFS) was created. The ESFS fulfils three functions: the prevention of a crisis, the management of a crisis, and crisis resolution. Crisis prevention starts with the regulation of the financial system to ensure its safety and soundness. This is enforced by supervisory authorities, which are responsible for ensuring compliance by financial institutions. If a crisis emerges, supervisors may take corrective measures to manage crisis. Finally, if the bank cannot continue to operate, it is resolved, restructured, or liquidated.

The EU single market remains the EU's most precious asset for citizens and businesses. It provides enormous opportunities for businesses, and a greater choice and better prices for consumers. But these benefits cannot be enjoyed if single market rules are not applied or implemented, or if they are undermined by other barriers.[18] The CRR and CRD represent a comprehensive substantive harmonization of banking law at European level (law on the books). However, until the establishment of the SSM, the MS were responsible for its application (law in action).

The European dimension of the financial and sovereign debt crisis was caused in particular by the lack of information exchange between the NCAs.[19] The supervisory authority of one MS applies the legal standards differently than the authority in another MS.[20] The basis for this is formed by the legal and factual room for maneuver of the NCAs. An efficient decision-making arrangement faces the challenge of balancing the tension between MS expertise on the one hand and supranational institutions with their independence from MS interests on the other.[21] In the multi-level system of banking supervision in the single market and monetary union, the stability of the European system is a public good. The coordination problems of the NCAs result in regulatory failure. Within the single European market - and even more so within the monetary union - the costs of inadequate supervision are not borne by one MS alone, but by all MSs and their citizens.[22]

Economic integration within the EU would be incomplete until MSs relinquished policies at the core of their sovereignty: budgetary, financial, and social policies and monetary policy.[23] The creation of the Banking Union was a crucial step towards completing economic integration into the EU. The Banking Union is the most advanced form of supranational legal and institutional integration within the single market.[24]

18 *von der LEYEN, Ursula. In: Monitoring the Application of European Union Law, Annual Report 2019, S. 12. https://ec.europa.eu/info/sites/info/files/file_import/report-2019-annual-report-monitoring-application-eu-law_en.pdf*

19 *KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020,, S. 105.*

20 *KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020, p. 31.*

21 *KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020, p. 31.*

22 *KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020, p. 31.*

23 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 1–2.*

24 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 2.*

Subsequently, in 2012, the Euro Summit announced the creation of a Single Supervisory Mechanism. It would become the first pillar of the Banking Union. The previously depoliticized regulation became politicized in the aftermath of the crises.[25] It was concluded by the Council that Article 127(6) TFEU would provide the legal basis for the transfer of banking supervision competences to the ECB. At the core of the SSM was the transfer of exclusive competences in banking supervision to the ECB. The ECB was entrusted with the large part of the supervisory competences provided by EU law to national supervisors at competent authorities. This included the authorization of all banks and the withdrawal of their license in the jurisdiction of the SSM as the sole competence of the ECB, ensuring compliance of credit institutions with prudential requirements, supervisory review, supervision on a consolidated basis, supervision of branches from credit institutions authorized in the EU, supplementary supervision of financial conglomerate, early intervention measures, limits to compensation of managers, administrative sanctions, and imposing structural changes in banks. The decentralization mechanism consists of a distinction between significant and less significant banks within the SSM. The exclusive competences of the ECB regard the direct supervision of the banks and banking groups, which are considered significant. The national supervisors supervise less significant banks based on the regulations, guidelines, or general instructions of the ECB, in order to ensure the consistency of supervisory outcomes within the SSM. For the exercise of these competences, the ECB had the specific powers provided in the SSMR.

Like the SSM Regulation, the SRM Regulation aims to shift decision-making competencies from the national to the European level in order to ensure the uniform application of substantive bank resolution law in the euro area MSs. The division of competencies between ECB and national (resolution) authorities is close to that as in SSM. SRM obliges and forces the national resolution authorities to take the measures required for implementation.

In 2015, as part of a package of measures to strengthen economic and monetary union, the European Commission issued a legislative proposal to establish EDIS. The aim of EDIS is to create a common deposit insurance mechanism separate from public budgets, to strengthen financial stability and to ensure that citizens have confidence in the protection of their deposits, regardless of the geographical location of a bank. However, to date no political agreement has been reached and so EDIS remains an unfinished project.

The main rationale for the Banking Union was to address the main exacerbating factor of the sovereign debt crisis: the link between sovereigns and banks. Following the financial crisis in 2008, the soundness of banks became dependent on the fiscal capacity of their respective MS to support them with public funds.[26] The creation of the Banking Union was a fundamental legal change in the single financial market. The Banking Union also led

25 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 184.*

26 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 217.*

to a process of differentiation of the single financial market, which became more deeply integrated within the euro area and more fragmented regarding the MS not participating in the euro.

With the Banking Union, banks became Europeanized or encapsulated in a European legal order. They are no longer subject only to national authorities or dependent on the fiscal capacity of their MS to rescue them. Another implication of the Banking Union is to repair the single financial market, which had been renationalized since the 2008 financial crisis.[27] We observe renationalization when there is a lack of implementation of single market commitments by the MSs or when the MSs abandon initiatives for supranational harmonization (e.g. in joint standard setting in the single market) and revert to national solutions instead.[28]

The creation of the Banking Union has brought at least three remarkable changes. Firstly, Banking Union is an example of judicialization in the EU as additional legal mechanisms are being set up between authorities from different MSs. Secondly, the Banking Union brings for multinational banks new opportunities to minimize operating costs based on benefits from uniform regulation across MSs and the associated greater predictability of changes. And thirdly, in context of Banking Union we also speak about executive federalism. There has been a delicate shift of competences towards a federal structure of the European Union, at least for the time being in banking regulation.[29] The system of competences of the SSM, which combined the competences of the ECB and national authorities in banking supervision, was also another institutional innovation in the sense that it is the most intensive transfer of national competences to the EU level. The SSMR included decentralization of operational tasks, preservation of tasks with national authorities within a framework akin to delegation, and aspects resembling a dual banking model.

The Banking Union is one of the priority European projects whose main objective is to create a more transparent, unified, and safer market for banks.[30] The Banking Union is a crucial step towards a genuine Economic and Monetary Union. A common system of uniform rules with uniform supervision by the European Central Bank allows for the consistent application of EU banking rules in the participating countries. In the Banking Union, EBA and ECB make a significant contribution to the defense against risks to the European financial system.

27 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337, p. 218–219.*

28 *RAUDLA, Ringa, SPENDZHAROVA, Aneta. Challenges to the European single market at thirty: renationalisation, resilience, or renewed integration? Taylor Francis Online, p. 1–17.*

29 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 230.*

30 *https://www.bankingsupervision.europa.eu/about/bankingunion/html/index.en.html*

However, not every MS of the European Union is also a member of the Banking Union. The main motivation for not joining a Banking Union is to retain competence at the level of the nation state. In a center of this approach is the postulate that the state is melting in the EU like sugar in coffee.[31] However, it is worth remembering here that the European Union is characterized by legal pluralism, dialogue and the renunciation of hierarchical solutions and last words.[32] In this regard, the principle of mutual trust is intended to ensure the unity and effectiveness of uniform Union law.

The TFEU conferred exclusive central banking competences in the EU to the European System of Central Banks (ESCB), comprising the ECB with its own legal personality and the national central banks (NCBs) of the participating MS.[33] The decisions are taken by the decision-making bodies of the ECB, the Governing Council and the Executive Board. The implementation of decisions is conducted by the whole ESCB, since the ECB is obliged to have recourse to the NCBs to carry out operations which form part of the tasks of the ESCB.

The Banking Union represents a multi-level governance model fusing together the supranational and national levels and converts them into a one European regulatory system.[34] The European Central Bank is entrusted with independent regulatory powers, including the ability to directly impose sanctions for the enforcement of such powers.

The ECB integrates the NCAs into its direct supervision by forming joint supervisory teams (JSTs). In this way, it activates the local capabilities of the NCAs, but at the same time increases the the risk of capture by special interests.[35] Legally, the ECB is permitted to enforce the EBA standards within the SSM with its own guidelines, to avert, specify or tighten them. The ECB's guidelines in indirect supervision are legally-binding vis-à-vis the NCAs. As part of its indirect supervision, the ECB can also issue "general instructions" to the NCAs. General instructions are binding on the NCAs and oblige them to take direct action vis-à-vis a large number of institutions.[36]

The Single resolution board, established by the SRM regulation, is a fully independent EU agency acting as the central resolution authority within the banking union. Together with the national resolution authorities of participating countries, it forms the SRM. The mission of the SRB is to ensure the orderly resolution of failing banks with minimum impact on

31 *Isensee, Am Ende der Demokratie – oder am Anfang?, Berlin 1995, S. 55. In: Ulrich Haltern, Europarecht und ich, JöR N.F. Bd. 68 (2020), i.E.*

32 *HALTERN, Ulrich. Europarecht und ich, JöR N.F. Bd. 68 (2020), i.E.*

33 *Art. 129(2) TFEU and 9.1 of the Statute of the ESCB and the ECB (Protocol No 4 on the Statute of the European Systém of Central Banks and of the ECB.*

34 *TEIXEIRA, Pedro Gustavo. The legal history of the European Banking Union: how European law led to the supranational integration of the single financial market. Oxford, UK: Hart Publishing, an imprint of Bloomsbury Publishing, 2020, xxv, 337. ISBN 978-1-50994-062-2, p. 103.*

35 *Kaufhold, AöR 2018, 86, 99.*

36 *KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020, S. 219.*

the real economy and the public finances of banking union countries and managing the single resolution fund.[37]

After the creation of the Banking Union in 2013, the Slovakia being a Euro-MS joined the European Banking Union with common supervision and common rules for crisis management procedures. The Czech Republic is not participating in the Banking Union. In Czechia is NCA and also NRA Czech National Bank. In Slovakia is NCA National Bank of Slovakia and NRA Slovak Resolution Council.

NCBs, too, have been influenced by the European integration process: they operate within the ESCB. NCBs are NCAs and NRAs in the framework of the BU.

1.3 Banking Regulation in Slovakia and Czechia

The modern regulatory trajectories of Slovakia and Czechia cannot be understood without recalling their shared constitutional and economic heritage. The peaceful dissolution of the Czech and Slovak Federative Republic on 1 January 1993 resulted not only in the establishment of two sovereign states, but also in the creation of two independent central banks – Národní banka České republiky (ČNB) and Národná banka Slovenska (NBS) – each inheriting institutional know-how from the former federal State Bank of Czechoslovakia. While both countries subsequently entered the European Union on 1 May 2004 under identical accession conditions, their approaches to monetary integration and financial-sector governance diverged significantly over time.

Slovakia proceeded rapidly on the path toward adopting the single currency, joining the euro area on 1 January 2009 after fulfilling the Maastricht convergence criteria. This move decisively anchored the Slovak banking sector within the structures of Economic and Monetary Union (EMU) and later, automatically, within the European Banking Union, which encompasses the Single Supervisory Mechanism (SSM) and the Single Resolution Mechanism (SRM). Consequently, prudential oversight of significant Slovak banks is exercised directly by the European Central Bank (ECB), while the NBS cooperates closely with the ECB in the performance of supervisory tasks. Slovak banks therefore operate under a unified, supranational supervisory regime in which regulatory standards – both "hard law" and "soft law" – are interpreted and enforced consistently within a centralized framework.

Czechia took a markedly different route. Although the Czech Republic expressed a treaty obligation to adopt the euro (with the permanent opt-out available only to Denmark), it has not yet set a timetable for euro-area accession and has remained outside the Banking Union. As a result, the Czech National Bank retains full sovereign authority over macroprudential and macroprudential supervision of Czech banks, as well as over crisis management and resolution. The Czech regulatory system must, of course, comply with all relevant EU directives and regulations, but its supervision remains nationally anchored and displays a higher degree of regulatory discretion. The ČNB regularly aligns

37 *https://finance.ec.europa.eu/banking-and-banking-union/banking-union/single-resolution-mechanism_en*

its supervisory practice with guidelines and recommendations issued by the European Banking Authority (EBA), yet – unlike NBS or ECB – its adherence to EBA "soft law" is voluntary and not legally enforceable. This means that the Czech system is stable and largely convergent with EU standards only because the ČNB chooses to follow EBA guidance; this alignment is institutional rather than legally mandatory and can, at least in theory, be altered unilaterally at any time.

These divergent choices have produced a structural asymmetry between the two countries within the EU internal market. Slovakia is fully integrated into the Banking Union's supervisory and resolution architecture, whereas Czechia remains within the Single Market but outside Banking Union mechanisms. This, in turn, raises the question whether such differentiated integration generates market fragmentation, particularly with respect to uniform supervisory standards, supervisory intensity, the application of the Single Rulebook, and the freedom of establishment of cross-border banking groups. Both countries host banking sectors dominated by subsidiaries of large foreign groups – many of them Austrian – yet the legal framework governing these subsidiaries differs substantially.

Finally, Czechia is currently engaged in an increasingly intensive debate on potential Banking Union membership. Policymakers, academics, and representatives of the financial sector are gradually reassessing the benefits and drawbacks of accession, considering not only prudential stability and supervisory coherence, but also broader economic, strategic, and political factors. Whether Czechia ultimately decides to opt into the Banking Union remains an open question, but it is evident that the divergence between the two countries provides a unique comparative setting for examining the implications of differentiated integration within the European Union's financial architecture.

1.4 Key features of the Slovak and Czech banking sector

The Banking Union was created and exists as a response to the successful or less successful functioning of the banking sectors. We get a very concrete picture of the functioning of banking sectors in the Czech Republic and Slovakia when we consider the interconnectedness of Czech and Slovak banks with their parent companies. It is not surprising that, thanks to their common history and established relationships, Austrian banks have subsidiaries in Slovakia and the Czech Republic. However, this fact is only of secondary importance. The main point is that the example below represents the linking of a parent bank from a Banking Union member country with its subsidiaries within and outside the Banking Union. Thus, from the perspective of the mother company (BU company), the Czech market is a qualitatively different jurisdiction where local legislation and administrative activities need to be more sensitive.

Major banks in Czechia are Česká spořitelna (ERSTE, Austria), ČSOB (KBC Belgium), Komerční banka (Societe Generale, France), Raiffeisenbank (Austria), UniCredit (Italy) a PPF Banka (Czechia). All of them, except for PPF, would be considered as significant banks.

These characteristics point to the high number of subsidiary banks operating in the Czech banking sector. Major banks in Slovakia are Slovenská sporiteľna (Erste, Austria), VÚB Banka (Intesa, Italy), Tatra banka (Raiffeisen, Austria), ČSOB (KBC, Belgium), Unicredit (Italy), Poštová banka (Slovakia). All of them, except of Poštová banka are significant banks. Here the same, these characteristics point to the high number of subsidiary banks operating in the Slovak banking sector.

On this basis, it can be said that, as Slovakia and the Czech Republic are two small countries, both are intricately linked economically with other EU (mainly BU-member) countries. For this reason, it is especially important that there are as few barriers as possible to the least costly operation of cross-border banking in these countries.

There are three convincing arguments based on which we could come to the conclusion that both the Czech and Slovak banking sectors are in nature remarkably similar. First, the characteristics of the Czech and the Slovak banking sectors indicate the higher resilience and stability compared to many other EU MSs. Second, both banking sectors show above-average ratios of the health of the banking industry compared to the Eurozone average. Third, both systems are characterized by the fact that each banking sector is mainly composed of subsidiaries of European parent banks in other MS.

The relationship between the European legislator and the MS enforcement level can be understood as a principal-agent relationship.[38] The legislation in the Czech Republic and Slovakia is similar for one simple reason - principal-agent relationship between EBA and the Czech National Bank works well. It can be said that the system based on the EBA's activities, combined with narrow cooperation within the ECB colleges, is a sufficient precondition for the Czech banking sector to be a stable part of the European banking system. However, this situation is only based on the correct practice of the Czech regulator. There is no guarantee that this situation will continue into the future.

1.5 Single Rulebook as Common Regulatory Basis for Slovakia and Czechia

The Banking Union was established on the basis of the Single Rulebook. The Single Rulebook is an EU-wide set of rules. The Single Rulebook is not a single coherent document, but a mixture of different rules, which together under this name apply to all MSs of the European Union. These rules deal, among other things, with capital requirements for banks, depositor protection and bank failure prevention and management.

The Single Rule Book is a fundament for Slovak and Czech banking regulation. Slovakia and the Czech Republic were obliged to implement the Single Rulebook. Both countries are also obliged to respond to amendments to the Single Rulebook. However, both countries implement EU law differently and this is also reflected in the implementation of the European banking regulation. Where this discrepancy lies and to what extent these differences are fundamental should we be answered in this thesis

38 KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020, p. 252.

1.6 European Banking Authority as Common Supervisor over Slovakia and Czechia

The European Banking Agency as an independent EU authority part of the ESFS established in response to the financial crisis contributes to the correct use of the Single Rule Book. EBA either provides technical advice or independently prepares drafts for technical regulatory and enforcement standards. The EBA is also responsible for the central task of establishing common regulatory and supervisory standards, even after the creation of the Banking Union. The guidelines, recommendations and the EBA's Q&A are counted as guidance.

All EU MSs are legally bound by the EBA's Guidelines. In BU-MS they will be applied by the ECB for Sis, and the NCAs for LSIs only. Whereas in non-BU-MS they are applied to all credit institutions by the NCAs.

In the areas defined by the banking acts (i.e., BRRD, CRD, CRR, DGSD), EBA and European Commission can comprehensively define standards for the NCAs with technical standards. EBA uses its Q&A tool to monitor the technical standards. The Q&A tool deals with questions on the banking acts and even on the TS and guidelines developed by itself, but not on the recommendations. The EBA adopts extensive and detailed regulations as guidelines, while it draws up specific behavioral expectations for individual NCAs and templates for application-related actions in the form of recommendations.[39] This level of regulation is equally legally-binding for the Slovak and Czech regulators, and eventually also for the regulated entities.

The EBA's supervisory guidelines and recommendations are intended to ensure uniform application of the law and administrative practice.[40] These instruments generally assume the functions of European administrative regulations.[41]

Most of the EBA's output is legally non-binding. Their application in the MSs is based on a comply-or-explain mechanism.[42] On the one hand, the MS thus legally retains the possibility to decide on its own whether to apply a particular EBA recommendation, or to decide not to apply it and to give reasons why not. Thus, this construction does not legally guarantee a uniform application of the rules in the way stated by the EBA in its documents. On the other hand, the comply-or-explain mechanism retains the advantages of delegating regulatory decisions to the MSs. The EBA informs the European Parliament, the Council and the Commission about the compliance practices of the NCAs and thus enables the EU institutions to take legislative action against perceived inconsistencies.[43] As a result, it is to be concluded that the stability of the financial sector in the EU is not based on solid legal foundations that would force the Slovak and the Czech NCAs to apply the law consistently in line with EBA documents.

39 *KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020, p. 123.*

40 *HÄRTEL. Handbuch europäische Rechtsetzung, 2006, § 13 Rn. 21.*

41 *KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020, p. 133.*

42 *KÖHLER, Lukas Philipp. Rulemaking in der Bankenunion. Mohr Siebeck. Tübingen. 2020, p. 146.*

43 *Art. 16 (4), Art. 43 (5) EBA Regulation.*

1.7 Conclusions: From the present to the future

Unlike in the 2008 financial crisis, banks are not the source of the problem anymore. But we need to ensure that they can be part of the solution of financial crisis in the future.[44] EU credit institutions are (on average) well capitalized and benefited from having implemented macro-prudential buffers and liquidity ratios, which were introduced as international financial standards by the so-called 2010 Basel III regulatory framework of the Basel Committee on Banking Supervision.[45] The EU plans to complete the implementation of the Basel III standards (also known as Basel IV) into EU law. The goal is to increase the strength and resilience of banks operating in the Union. In doing so, it is important to consider the specificities of the banking sector in the EU and the specific situation in MSs.[46]

According to the ECB Financial Stability Review of May 2021 risks to financial stability remain elevated and have become more unevenly distributed. Thus, financial stability vulnerabilities as identified therein cannot be underestimated, considering, inter alia, the following. First, the increased importance of climate-change-related transition and physical risks. Second, credit institutions' persistently low profitability, which to a certain extent is caused by the low level of interest rates. Third, delays in sustainable economic recovery. Fourth, higher credit risks are due to weaknesses in some sectors of the economy despite strong public support and government guarantees.[47]

The Czech and Slovak approach to implementation of these reforms would provide us an image of the evolution in discrepancies between Czech and Slovak banking sectors.

The Commission's proposal to amend CRD IV aims to strengthen the regulatory and supervisory environment for banks operating in the EU by removing loopholes for third country branches, strengthening and harmonizing supervisory tools and powers in important areas, ensuring that supervisors are sufficiently independent of economic and political influence, and integrating environmental, social and governance risks.

By adopting the Banking Package, the EU will strengthen the Banking Union and reduce risks in the financial system. The banking package consists of proposed amendments to CRD VI, BRRD and CRR III. As a result, the banking sector will have to implement many changes. The Commission's amendment to the CRR aims to strengthen and facilitate the allocation of capital and liquidity across banking groups in Europe without significantly increasing their capital requirements. The framework for credit risk and operational risk will be further improved and supported by a 'minimum exit level' aimed at reducing unwarranted differences in banks' risk measurement.

44 *See at: https://www.bankingsupervision.europa.eu/press/interviews/date/2020/html/ssm.in200623~e668f871fa.en.html.*

45 *Legal Aspects of the Single Monetary Policy in the Euro Area: From the establishment of the Eurosystem to the pandemic crisis. Christos V. Gortos. Third fully updated edition. 2022, p. 70.*

46 *STANJURA, Zbyněk. Minister of Finance of the Czech Republic, 8.11.2022 (ECOFIN).*

47 *GORTOS, Christos V. Legal Aspects of the Single Monetary Policy in the Euro Area: From the establishment of the Eurosystem to the pandemic crisis. Third edition. 2022, p. 71.*

The scope of CRR III and CRD VI includes changes to the standardized approach for credit risk, the Internal Ratings Based (IRB) approach to credit risk, the calculation of the credit valuation adjustment (CVA), the operational risk framework, and the output floor that limits the capital contribution from model risk. A critical point is the amendments to the CRR and CRD to incorporate ESG requirements (environmental, social, governance - factors).

In addition, the proposal includes a new framework for the regulation and supervision of third country branches (TCBs) in the EU. Furthermore, modifications to Pillar 2 (P2R) and Systemic Risk Buffer (SyRB) requirements accompany the introduction of an exit floor, as well as an expansion of the definition of entities to be included in the scope of prudential consolidation, capturing FinTech ownership and involvement in financial activities.

The EBA has been given the power to centralize the publication of annual, semi-annual, and quarterly institutional prudential information for the largest institutions in the EU.

In addition, the proposal includes provisions on the independence of competent authorities and the handling of conflicts of interest, the extension of the supervisory powers of competent authorities in the EU to create a common standard, the introduction of a requirement to carry out a fitness and probity assessment of directors against a common standard, clarification of the correlation between default or likely default and a change in the supervisory approach to benchmarking expected credit risk losses for the purposes of calculating own funds requirements.[48]

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48 *See more: https://finance.ec.europa.eu/news/commission-welcomes-political-agreement-eu-banking-package-2023-06-27_en*

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Implementation of Artificial Intelligence, Automation and Robotization in Financial Business Centers

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Abstract

Background: Artificial intelligence (AI), automation, and robotization are transforming financial business centers globally, but research on their implementation in Slovakia remains limited.

Aim: This study investigates how AI, automation, and robotization are implemented in Slovak financial business centers and evaluates their impact on competitiveness.

Methods: A qualitative multiple case study was conducted, including interviews with representatives from four Slovak financial business centers and detailed case analyses.

Results: All centers have integrated AI, automation, and robotization into various business processes, with differing levels of maturity. These technologies enhance operational efficiency and competitive performance.

Recommendations: Organizations should accelerate technology adoption, invest in employee upskilling, and strengthen collaboration with academic institutions to address implementation challenges. Further research could expand the study to additional centers in the CEE region.

Practical relevance/Social implications: Findings support strategic decision-making in Slovak and Central European financial centers, promoting competitiveness, efficiency, and sustainable development.

Originality/Value: This is the first in-depth study of AI, automation, and robotization implementation in Slovak financial business centers, filling a regional research gap and providing actionable guidance for managers and policymakers.

Keywords

Business Centers, Artificial Intelligence, Automation, and Robotization, Slovakia, Central and Eastern Europe

JEL Codes

M15, G32, O33

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Introduction

In recent years, many multinational corporations have increasingly adopted automation, robotization, and artificial intelligence (AI) within their business processes to enhance efficiency and reduce operational costs. Business service centers (BSCs) are no exception, as the pressure to remain competitive in a dynamic global environment drives them to implement advanced technologies. Financial BSCs, in particular, face the dual challenge of optimizing internal operations while meeting evolving client and market expectations. Slovakia has emerged as an attractive location for such centers due to its skilled workforce and favorable business climate (SARIO, 2022). Despite this trend, empirical research on the actual implementation of AI and related technologies within financial BSCs in Slovakia remains limited.

To better understand the nature of these entities, it is important to consider how they are defined in the literature. Schuppan (2009) describes business service centers as "largely independent organizational units that provide cross-border services to multiple internal clients, resulting in the provision of networked services." Gospel and Sako (2010) define them as "organizational units that integrate company resources (e.g., human capital, organizational structure, and IT systems) to support and deliver services to internal customers." Similarly, Schultz and Brenner (2010) refer to BSCs as "partially autonomous business units that operate consolidated support functions, such as accounting and human resources, and provide services to internal clients." These definitions highlight the hybrid nature of BSCs – combining centralized operations with a degree of autonomy – and underscore their strategic importance in modern enterprises.

This lack of empirical insight makes it difficult to evaluate the real impact of digital technologies on everyday operations and strategic priorities in the regional context. Moreover, it raises questions about how these innovations influence organizational structures, employee roles, and corporate culture. Understanding these dynamics is essential for both practitioners and policymakers seeking to navigate the implications of digital transformation in knowledge-intensive industries.

The aim of this article is to examine how artificial intelligence, automation, and robotization are being implemented in four selected financial business service centers operating in Slovakia. A qualitative case study approach was applied, utilizing semi-structured interviews with senior representatives of the centers, supplemented by publicly available secondary data. This study seeks to identify both the benefits and challenges of digital transformation in financial BSCs, and to contribute to the growing body of literature in this underexplored area.

We identify three research questions:

RQ1: In which areas and processes do financial business service centers implement artificial intelligence, automation, and robotization?

RQ2: What experiences and challenges do representatives of financial BSCs describe in relation to the adoption of these technologies?

RQ3: How does the implementation of AI and robotization influence workflows and organizational culture within financial business service centers?

To address these research questions, a qualitative multiple case study was conducted, as detailed in the Methodology.

1 Literature review

Before analyzing AI adoption in Financial Shared Services (FSS), it is important to clarify key concepts. Artificial Intelligence (AI) is an umbrella concept influencing multiple disciplines, encompassing systems capable of performing tasks that typically require human intelligence, ranging from narrow AI applications, such as Google Assistant, to the aspirational strong AI capable of human-level general intelligence (Kumar, Gupta, & Sharma, 2016; Müller & Bostrom, 2016). Automation refers to technology or systems that execute tasks previously performed by humans, often following pre-programmed rules, thereby freeing humans from repetitive or time-consuming physical and cognitive activities (Evans, 2017). Robotization is the technology for developing machines, called robots, that replicate human actions, often performing repetitive or hazardous tasks, and can be combined with AI to learn and act autonomously (Parasuraman & Riley, 1997).

The transformation of FSS under the influence of AI has emerged as a key trend in corporate finance. As Zhang (2020) notes, FSS platforms deliver cost savings and increased operational efficiency, but their full potential is realized only with AI and big data. Evolutionary and classification algorithms enable process optimization, improved data accuracy, and predictive modelling.

Recent studies emphasize that AI adoption is increasingly strategic. Kumar et al. (2022) highlight that AI-driven decision-making enhances risk management and forecasting. Patel and Singh (2023) show that integrating AI with RPA in Shared Service Centers (SSC) improves operational resilience and reduces human error.

According to KPMG (2023), 98% of organizations are testing generative AI, with more than half planning expansion within hybrid models. Dement & Robinson (2023) add that AI adopters report higher performance but face challenges like skill shortages, weak strategic leadership, and low data standardization. Deloitte (2023) confirms AI has moved into core operations, used for document processing, data summarization, and translation, reshaping daily financial tasks.

Strategic objectives of SSCs have evolved. Deloitte (2021) notes a shift from cost reduction to process standardization and efficiency. Cost optimization remains important but is secondary to delivering business value. Broader trends include developing data analytics skills, adopting remote work, retaining talent via corporate culture and flexibility, and continuous digital integration.

RPA remains central in SSC operations. As Schreiber (2019) outlines, RPA evolves through three stages: rule-based automation, end-to-end automation with virtual workers, and cognitive automation making data-driven decisions independently. Lee et al. (2022) confirm that combining RPA with AI analytics enhances process efficiency, especially in invoice processing and reporting.

AI adoption also increases risks. Zhang (2020) warns of uniform AI decisions, potential data leakage, and algorithm limitations tied to training data quality. Nguyen et al. (2023) and Rao & Verma (2024) highlight the importance of workforce adaptability and continuous upskilling for AI success.

Sun (2021) describes AI as "the soul of new retail," bridging physical and digital environments, enabling service personalization, and driving automation. Hofmann & Böhme (2022) show AI transforms accounting from record-keeping to predictive and advisory functions, enhancing strategic decision-making in SSCs.

Global studies (Zhang, 2020; KPMG, 2023; Dement & Robinson, 2023; Deloitte, 2023) provide valuable insights, but mainly reflect large multinational contexts. Local specifics, particularly in Central and Eastern Europe (CEE) including Slovakia, are underexplored. Novak et al. (2022) and Horváth & Mészáros (2023) show AI adoption in CEE SSCs varies in organizational readiness, workforce skills, and technology.

While global studies provide valuable insights into AI-driven transformation, regional studies are needed to capture the specific conditions and maturity levels of CEE financial service centers. Therefore, this article analyzes AI adoption in selected Slovak financial business centers and assesses how global trends are reflected locally. Integrating recent research and surveys provides a comprehensive understanding of critical success factors and challenges in AI-enabled SSC transformation.

2 Methodology

The introductory part of the article and the selection of research methods were based on a thorough review of domestic and international academic literature registered in the Web of Science and Scopus databases. These theoretical sources served as a foundation for identifying the literature gap, which highlighted the insufficient exploration of the implementation of artificial intelligence, automation, and robotization in financial business centers, particularly within the context of the Slovak Republic.

The empirical part of the research was developed using a qualitative case study approach. Semi-structured interviews were conducted with senior representatives of four selected financial business centers operating in Slovakia between November 2022 and April 2023. In accordance with confidentiality agreements made between the authors and the participating centers, the names of the organizations and the individuals interviewed are not disclosed in this article. The information obtained through these interviews could not be sourced from publicly available materials and was essential for the development of the study. To ensure data reliability, all interviews were recorded (with participant consent) and subsequently transcribed for systematic analysis. Thematic coding was applied to identify recurring patterns, contrasts, and unique insights across cases. This analytic process enabled a structured comparison of implementation practices, perceived benefits, and challenges experienced by the studied centers.

The selection of cases was guided by the objective of examining the most representative examples of financial business centers in Slovakia. All four centers have foreign parent companies and operate in cities with the highest concentration of shared service and business centers in the country. The cases differ in size, year of establishment (ranging from 1992 to 2017), and the scope of provided services. This heterogeneity made it possible to capture varying levels of digital maturity and diverse approaches to AI implementation. The chosen cases therefore reflect the broader structure of the financial shared services sector in Slovakia.

The primary data obtained from the interviews were complemented by secondary data from official company websites and the online portals of national institutions promoting business development in Slovakia. This triangulation of sources increased the robustness of the findings and reduced the risk of bias. To further enhance reliability, interview transcripts and the final interpretation of results were reviewed and confirmed by the participating respondents. This respondent validation ensured accuracy and credibility in the presentation of empirical evidence.

This study has several methodological limitations typical of qualitative research. The relatively small sample size and sector-specific focus limit the generalizability of the findings. Moreover, the research is geographically restricted to Slovakia, which constrains cross-national comparisons. However, these limitations were mitigated through data triangulation, careful case selection, and validation of interpretations with respondents. Future research should expand the analysis to other sectors and countries in the Central and Eastern European region to strengthen comparative insights and external validity.

The described methodological design ensured that the collected data directly supported the research aim of assessing competitiveness impacts of AI implementation.

3 Results

The following table provides an overview of the basic attributes related to the analyzed business centers.

Table 1: Key Indicators of the Studied Business Centers

Business Center	Main Activity	Location	Established	Number of Employees	Country of Origin
BC 1	Financial Services	Bratislava, Košice, Banská Bystrica	1992	4000	USA
BC 2	Financial Services	Košice	2013	300	Switzerland
BC 3	Financial Services	Bratislava	2016	800	USA
BC 4	Financial Services	Bratislava	2017	330	Germany

Source: processed by authors

All centers operate in the field of financial services and are located in major Slovak cities such as Bratislava, Košice, and Banská Bystrica. Their years of establishment range from 1992 to 2017, indicating both long-standing and more recently founded operations. The number of employees varies significantly, from 300 to 4,000, reflecting differences in scale and maturity. The centers originate from diverse countries, including the USA, Switzerland, and Germany, illustrating the international nature of the business service sector in Slovakia.

3.1 Business Center 1

BC 1 established its International Services Centre (ISC) in Bratislava in 2003 as part of its global strategy to optimize corporate processes. Employing over 5,000 specialists from 80+ countries, the center provides IT services, process automation, data analytics, and digital innovation to global clients (Online Interview, 2023).

A distinctive feature of BC 1 is its strong emphasis on robotic process automation (RPA) and AI-driven process optimization, which enhance scalability, reduce costs, and ensure operational accuracy. Continuous improvement initiatives such as internal hackathons, innovation labs, and AI-focused training programs support digital maturity and foster a culture of innovation (Online Interview, 2023). These initiatives exemplify the theoretical dimension of organizational readiness highlighted in the literature (Zhang, 2020; Kumar et al., 2022), demonstrating that strategic alignment of technology, processes, and human resources is critical for successful AI adoption.

BC 1's collaboration with academic institutions primarily aims to strengthen AI-related competencies and applied research. These partnerships facilitate curriculum development in automation and data analytics, contributing to the company's leadership in intelligent business services (Online Interview, 2023). This reflects the workforce adaptability and collaboration with academia dimensions identified in prior studies (Nguyen et al., 2023; Hofmann & Böhme, 2022).

3.2 Business Center 2

BC 2 has operated in Slovakia since 2007, with centers in Bratislava and Košice that support global telecommunications and IT infrastructure. Employing around 2,000 professionals, the Slovak operations specialize in network management, cybersecurity, and AI-enhanced support systems (Personal Interview, 2023).

AI technologies, including digital assistants and predictive maintenance tools, are integrated into network operations to increase uptime and reliability. These tools enable proactive incident resolution, improved service quality, and reduced operational risk. These practices illustrate process standardization and efficiency as described in Deloitte (2021) and align with theoretical perspectives on AI-enabled operational optimization (Patel & Singh, 2023).

Cooperation with local universities focuses on AI applications in network analytics and automation, ensuring access to a skilled talent pool in cybersecurity and digital systems (Personal Interview, 2023). This supports the human capital development dimension, emphasizing continuous upskilling to maintain AI readiness (Rao & Verma, 2024).

3.3 Business Center 3

BC 3 was established in Bratislava in 2007 and provides regional support in finance, procurement, and IT. It plays a strategic role in the company's digital finance transformation, using AI-driven tools and RPA to automate processes such as invoice processing and order-to-cash management (Personal Interview, 2022).

AI and analytics applications have significantly increased process transparency, efficiency, and decision-making quality. The SSC serves as a testbed for digital innovation, piloting and scaling emerging technologies before global rollout. These initiatives demonstrate the integration of technology adoption with organizational learning, echoing findings from Hofmann & Böhme (2022) on AI transforming accounting and finance into analytical and advisory functions.

Collaborations with Slovak universities primarily support research and training in financial analytics and automation technologies, ensuring a continuous flow of skilled digital professionals (Personal Interview, 2022). This aligns with theoretical frameworks emphasizing continuous workforce development as a critical success factor in AI adoption (Nguyen et al., 2023).

3.4 Business Center 4

BC 4 launched its Business Services Centre in Bratislava in 2017 to centralize global financial operations. With approximately 300 professionals, the center functions as a Centre of Excellence for automated finance processes (Online Interview, 2023).

AI and machine learning models are applied to improve financial forecasting, detect anomalies, and automate transactional workflows. Cognitive automation and smart reporting tools enhance process reliability and data-driven decision-making. These practices illustrate cognitive automation and reflect theoretical insights on combining AI and RPA for operational excellence (Lee et al., 2022; Patel & Singh, 2023).

BC 4's collaboration with academic institutions focuses on AI applications in accounting automation and data analytics, supporting workforce upskilling and fostering innovation within the digital finance domain (Online Interview, 2023). This reinforces the human capital and collaboration dimension identified as critical in AI implementation literature (Nguyen et al., 2023; Rao & Verma, 2024).

3.5 Summary of Findings

Tables 2, 3, and 4 present an overview of the findings and answers to the research questions. The findings in the tables are organized according to the individual cases studied.

Table 2: Areas and processes where AI, automation, and robotization are implemented, and how these technologies are integrated

BC 1	Automation and RPA used in finance, HR, procurement; integrated through global digital platforms. AI used for data analytics and cognitive automation.
BC 2	AI used in predictive network maintenance and digital assistants. High-level automation in network monitoring and technical support.
BC 3	RPA applied to finance (invoice processing, record-to-report). AI tools enhance strategic financial planning. Focus on process standardization.
BC 4	AI and robotization applied to accounting. Routine tasks fully automated. Acts as a Centre of Excellence for global process automation.

Source: processed by authors

Table 2 illustrates the diverse areas and processes where AI, automation, and robotization are applied across different business centers, including finance, HR, procurement, technical support, and accounting. Each center employs these technologies in ways ranging from routine task automation and process standardization to predictive maintenance and strategic planning. Integration is consistently achieved through global digital platforms and advanced AI tools, enabling enhanced efficiency and the establishment of Centers of Excellence.

Table 3: Experiences and challenges with adopting these technologies

BC 1	Positive transformation noted; major investment in workforce upskilling. Collaboration with academia supports implementation.
BC 2	Automation improved service reliability. Challenges in keeping talent pipeline full in tech-specialized fields.
BC 3	Generally positive experience with measurable improvements in efficiency. Change management and continuous training are critical.
BC 4	High degree of automation achieved. Key challenge: shortage of qualified workforce, especially for multilingual roles. Administrative hurdles for hiring non-EU staff.

Source: processed by authors

Table 3 summarizes the positive impacts of AI and automation adoption across the business centers, highlighting significant investments in workforce upskilling and collaboration with academic institutions. While automation has improved service reliability and operational efficiency, all centers face challenges related to talent shortages, especially in specialized technical and multilingual roles, as well as administrative barriers for hiring international staff. Continuous change management and training emerge as critical success factors to sustain the benefits of technological transformation.

Table 4: Influence on workflows and organizational culture

BC 1	Significant shift towards digital workflows. Collaborative culture with emphasis on innovation and continuous improvement.
BC 2	Streamlined operations, faster issue resolution. Culture values adaptability and proactive IT solutions.
BC 3	Improved accuracy and process efficiency. Culture focused on lean operations, analytics-driven decision-making.
BC 4	Manual work significantly reduced. Culture shifting towards innovation and efficiency. Efforts to upskill staff reflect changing roles and competencies.

Source: processed by authors

Table 4 highlights substantial shifts towards digital workflows and automation across all business centers, leading to more efficient, accurate, and streamlined operations. Each center reflects a cultural emphasis on innovation, adaptability, and data-driven decision-making, supported by continuous efforts to upskill employees and align competencies with evolving job roles. These transformations indicate that AI and automation are not only optimizing processes but also reshaping organizational culture to support ongoing improvement and agility. Overall, the findings demonstrate that AI implementation enhances competitiveness primarily through process efficiency, digital maturity, and workforce adaptability, directly addressing the study's research aim.

4 Discussion

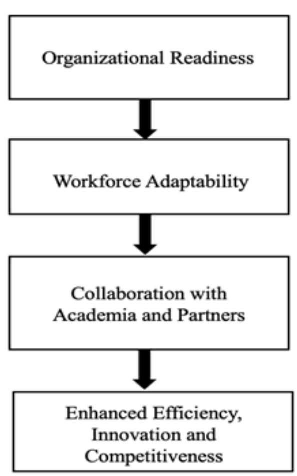
The analysis of the four Slovak financial business centers (BCs) shows that AI, robotic process automation (RPA), and robotization are applied across finance, HR, procurement, technical support, and IT infrastructure, with varying maturity levels. For example, BC 3 uses RPA for invoice processing, BC 2 integrates AI for predictive network maintenance, and BC 4 functions as a Centre of Excellence for process automation. These findings align with prior research emphasizing AI and RPA for process optimization and operational accuracy (Lee et al., 2022; Schreiber, 2019; Patel & Singh, 2023), representing the technological efficiency dimension of the proposed model.

Workforce development and collaboration with academic institutions are critical for successful AI adoption. BC 1 organizes hackathons and AI training, BC 4 focuses on accounting automation, and BC 2–3 support specialized skills in network and financial analytics. These practices ensure continuous learning and access to qualified professionals, reflecting human readiness in the conceptual model (Nguyen et al., 2023; Rao & Verma, 2024; Hofmann & Böhme, 2022).

Organizational culture also plays a key role. All BCs have shifted toward innovative, adaptable, and data-driven practices: BC 1 emphasizes collaboration and innovation, BC 3 focuses on analytics-driven decision-making, and BC 4 actively reshapes roles through cognitive automation. These observations align with literature highlighting the need for alignment of leadership, processes, and workforce capabilities (Kumar et al., 2022; Hofmann & Böhme, 2022), corresponding to organizational readiness and culture.

Local contextual factors influence AI strategies in Slovakia and the CEE region. Regulatory constraints, labor policies, and workforce shortages present challenges, as seen in BC 4's administrative hurdles for non-EU hires. These findings demonstrate that global best practices must be adapted locally, representing the local context dimension (KPMG, 2023; Deloitte, 2023; Novak et al., 2022).

Figure 1: A conceptual model of successful AI implementation in BCs



Source: processed by authors

Figure 1 synthesizes empirical findings and theoretical insights into a conceptual model. Each dimension corresponds to observed practices across BC 1–4, illustrating how technology, human readiness, organizational culture, and local context collectively enable efficiency, innovation, and competitiveness.

Overall, AI implementation enhances competitiveness through process efficiency, workforce adaptability, and digital maturity. Success depends on the integrated management of technology, people, organizational culture, and local contextual factors. This framework provides practical guidance for managers and policymakers while supporting future research on AI-driven transformation in the CEE region.

Conclusion

The implementation of AI, automation, and robotics in Slovak financial business centers significantly enhances operational efficiency, accuracy, and organizational adaptability. The case studies demonstrate that organizational readiness, workforce adaptability, and collaboration with academic institutions are the key success factors for effective AI integration, confirming the theoretical dimensions identified in the literature (Zhang, 2020; Kumar et al., 2022; Hofmann & Böhme, 2022; Nguyen et al., 2023).

These factors not only support internal process improvements but also translate into external competitive advantages, strengthening the centers' market position and reinforcing the role of the CEE region as a hub for business services. The findings highlight that AI adoption is not merely a technological upgrade but a strategic transformation, requiring alignment of culture, processes, and human capital to realize its full potential.

Practically, the results inform strategic innovation management by emphasizing the importance of agile transformation, continuous workforce development, and investment in localized AI solutions tailored to regulatory, labor, and infrastructural contexts. Policy and educational implications include promoting public–private partnerships, fostering collaboration between business centers and universities, and supporting continuous professional development to build sustainable talent pipelines and enable long-term AI adoption.

Overall, AI and automation function not only as tools for operational efficiency but as strategic enablers that, when implemented with supportive culture and governance, enhance competitiveness at both organizational and regional levels. Future research could expand the scope of case studies, explore sector-specific AI applications, or investigate the long-term impact of AI on workforce skills and roles, providing further guidance for managerial and policy decisions in CEE financial centers.

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Macroeconomic Costs of the Energy Transition in the Czech Republic

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Abstract

Background: Carbon neutrality and the entire energy transformation, especially of electricity supplies, lead to a change in the current energy paradigms. The past modelling approaches can lead to errors if not modified properly.

Aim: In this article we estimate the lower-bound of direct macroeconomic costs of the proposed electric energy mix change in the Czech Republic.

Methods: We augment the physical electric energy balance model with seasonally (monthly adjusted) estimated hourly average electric prices to show the economic difference between the yearly energy balance and import costs due to seasonal price patterns. This simple economic model is then applied on proposed future energy mix stemming from State Energy Policy (SEK) that does not consider the seasonal price patterns at all, and the paper goal is to provide the approximate magnitude of such an error. Our backward simulation imposing past prices and seasonal patterns on future energy mix is conservative, i.e., provides lower-bound estimate of the economic effect but also allows us to avoid future price and future consumption prediction errors.

Results: We show that the envisaged change in production mix leads to a direct increase in net imports that are comparable to the value above 0.5% GDP. When considering the fiscal multiplier, the total negative impact shall be around 1% GDP, annually. As the Czech economic growth is not stellar, the implied GDP decrease can further worse economic prospects.

Practical relevance/social implications: Models used by the state underestimate total costs and potential social impact of economic shrinkage.

Value: State energy policy shall be revised considering substantial effect of seasonal price variations leading to fiscal imbalances.

Keywords

Energy transformation, Czech Republic, Import dependency, Trade balance, Transition costs

JEL Codes

Q41, Q43, Q47, Q48, F17, F47, E17

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Introduction

Carbon neutrality and the entire energy transformation, especially of electricity supplies, lead to a change in the current energy paradigms. In addition, the changed geopolitical situation has reminded us of the energy security issues of the oil crisis. For example, Stegen (2011) deals with strategic use of energy and security issues while Guarascio et al. (2025) evaluate recent energy vulnerability and resilience in the EU regarding the imported energy inputs (mainly oil and gas). While energy generally includes the production of heat, cold and electricity, in this article we will focus on the latter part. In addition to the intended primary objectives, i.e., the transition from fossil fuels, the transition strategy has a few side effects in the electricity sector that must be dealt with.

The electricity sector is perceived either as the primary target of the transformation or as a source of a new, carbon-free electricity energy that will replace fossil fuels in other areas, especially industry and heating. Such a dichotomy unfortunately fuels biased partial views on the electricity industry and thus leads to distorted conclusions due to the unrealistic assumptions, and neglected impacts of regulation and omitted fundamentals.

The rapid ultimate change in the production mix means that old time-proved models of energy sectors are no longer suitable, as some long-standing (and therefore often silent and overlooked) assumptions cease to apply – as we will show later. Unfortunately, these facts are not given due attention both in policymaking and in the analysis of possible first-round or second-round effects.

It is worth pointing out the prerequisites for the liberalization of network industries. A key moment in European policies at the end of the last century was the separation and preservation of the network infrastructure with the character of a natural monopoly, which is the cheapest solution from a social point of view, and the enabling of equal competition of services or products on this infrastructure (the initial situation in the Czech Republic and the EU is described in Lizal, 2000).

From today's point of view, the policy of liberalization applied to telecommunications has led to an improvement in services. The energy sector, especially because of the original natural national diversification of production mixes and excess existing capacities, did not look like a problem after successfully coping with the emission limits of pollutants. However, the principle of neutrality has been violated by the gradual regulatory preferential inclusion of new (so-called emission-free) intermittent sources (RES). The growing problem of new inequality (subsidies, regulatory preference over other sources) has been de facto legislatively implemented as a new type of market (or rather regulatory) failure, which is now emerging to the surface in the form of (surprising) rapid price changes, volatility, and investment havoc in transmission and distribution networks. The electricity industry, for a long time being an industry where a long-term perspective worked perfectly, has become a highly volatile and risk-unpredictable part of the economy. Recently, however, so far theoretical risks of endangering the stability of networks have materialized in the form of an April 2025 blackout in Spain affecting 50 million people for nearly a day or a large outage in July in the Czech Republic affecting 3 million people for a few hours.

In the following sections of our article, we first explain common misconceptions and show why common price patterns emerge, and then we use these patterns in our simulation model to show that yearly physical balance of electricity generation and consumption can be associated with huge macroeconomic fiscal imbalance. The quantitative goal of the article is to quantify the omitted direct macroeconomic costs of the energy mix change in the proposed Czech State Energy Policy proposal.

1 The Emergence of Non-Market Competition: Market Separation

Perhaps the best and most important example of a change that documents both the confusion of concepts in the public space and regulatory failures is the approach to uncontrollable electricity production sources (RES) and the policy of emission allowances (ETS).

For a long time, the energy sector in the EU has not been developing according to competition on the market, but according to the impact of state interventions, as the price of emission permits depends directly on political decisions. The fact that permits are traded does not mean that the price is not a direct consequence of the political decision on how many of them were or should be available. The inconsistency of policies over time and permanent revisions act as an investment repellent: if there is a periodic tightening that changes the original political objectives, then the new goals are also implausible from the point of view of risk management of classic investment plans, and the area becomes the domain of speculative investments. The public interest is then solved by new subsidies that further distort the investment environment, and we begin to move in a vicious circle. While the investment decisions and the effects of ETS are subject to scholarly exercises often, our contribution focuses on a different direction.

Unfortunately, the total impact of regulations is also determined by the degree of misunderstanding of how the energy industry works in the real world. There are **less visible but equally serious impacts than the allowances described**. In the following short exposition, we start with Lizal (2025). The price of electricity for consumers is de facto created as a combination of results on two "markets" that are recently, due to regulatory policy-induced changes, moving apart in terms of price while originally these markets were almost identical. In addition, typically prices from only one of these two markets are presented – the wholesale commodity price.

Electricity is the only product that **we cannot store cheaply and massively**. Production adapts to demand at every moment to maintain a **physical (electric) balance between demand (consumption) and supply (production)**. However, the massive involvement of uncontrollable sources leads to a change in the quality (characteristics) of the distribution network. Previously, all sources were controllable, and it was possible to increase and decrease their output (very cheaply) as needed. As a result, there was no big difference between the price of electricity and electricity for power and stability regulation. As all sources operated close to their economic optimum the downward or upward deviation led to only a minimal increase in costs (or decrease in efficiency). Therefore, the prices of regulatory and basic energy were highly correlated, and regulation has been with a minimal surcharge.

Now, the RES (renewable energy sources) that are in the network system have a priority (which is given regulatory) and require other sources to adapt to their production. That is why there is a growing price difference between the power electricity for the so-called base load and the electricity needed for stability and **grid regulation**. However, the more RES, the greater the volatility of the regulatory component needed, and the greater the costs for providing it. That can only result in a growing difference between the baseload and balancing energy component prices. The baseload and balancing electricity markets have not only separated but are still diverging from each other. Increasingly more balancing electricity is needed, and at the same time there are fewer sources available that were used to provide it cheaply. In addition, these sources (formerly coal, today typically steam-gas) are further burdened with ever increasing price of CO_2 permits in ETS. Both permit price growth and increased scarcity of the balancing resources do work in the same direction to increase total balancing costs.

Electricity, as a baseload, may thus become cheaper, but as we document in the following section, due to the need for balancing electricity for the functioning of the network and other distribution costs, the total final consumer cost increases. In addition, expensive new sources (steam-gas) shall be added to make it possible to manage the network. Therefore, economic impact modelling must account for these specificities of influencing prices.

2 Regulatory Failure: Investor vs. National Economic Perspective

These issues mentioned are not new, see Ueckert et al. (2012), Idel (2023) or BoA(2022). The usual argument that RES saves conventional fuels and therefore their increasing share will lead to cheaper electricity has limited validity both due to the size of the share of RES in the energy mix and the composition of the mix itself, as will be shown in the following exposure. The "cheap" benefit applies only to a small share of RES typically up to a few percent. With the growing share of RES, they are already displacing other cheap sources, such as nuclear or water, or even cannibalizing themselves if employed massively. It is more difficult and costlier to maintain the stability of the grid and consequently the final total price of electricity is rising. For example, the simple earlier estimates, e.g., Eschenbach (2015), have claimed the residential costs of electricity shall rise by 0.02cents per each additional kW of RES capacity.[1] While these earlier academic papers and calculations have not received much attention so far and have been largely ignored in policymaking,

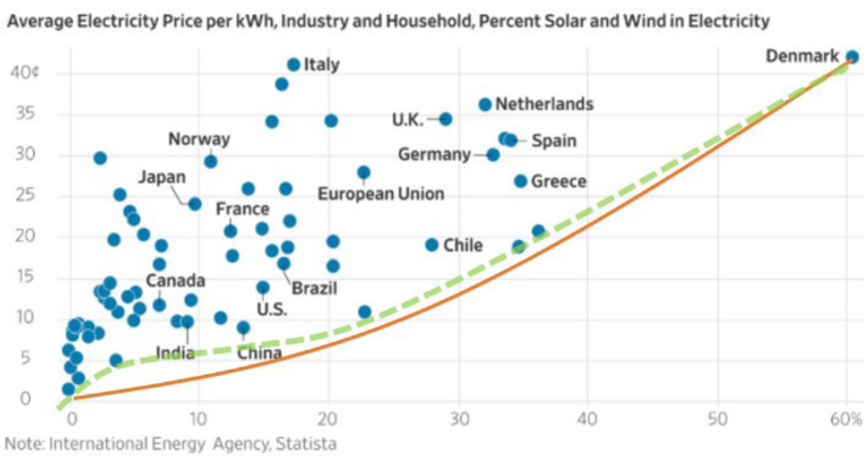
1 *https://wattsupwiththat.com/2015/08/03/obama-may-finally-succeed/*

Lomborg (2025) practical visualization of current consumer prices (see Figure 1) led to vociferous public debate.

The simple non-linear frontier estimation has an increasing pattern (orange line) while the spline (light green dotted line) shape resembles the Ueckerdt et al (2013) economy-wide costs predictions for Germany in Figure 2.

The argument of the production cheapness of electricity from wind and solar is simply not correct for consumers or from an economic (social costs) point of view. It is the investor's view of his **investment costs** (so-called LCOE, see, e.g. EIA, 2022). LCOE represents the average price of electricity sales that ensures the investor's required return (profit). But this is a price that the customer – i.e., literally speaking, the person at the electricity socket – is not interested in at all. That customer pays the total costs price that is different and higher, because it includes all the costs of maintaining the stability of the network, its development and covering the risks of non-supply.

Figure 1: Electricity Prices and RES Share



Source: Lomborg (2025), estimated frontiers: authors.

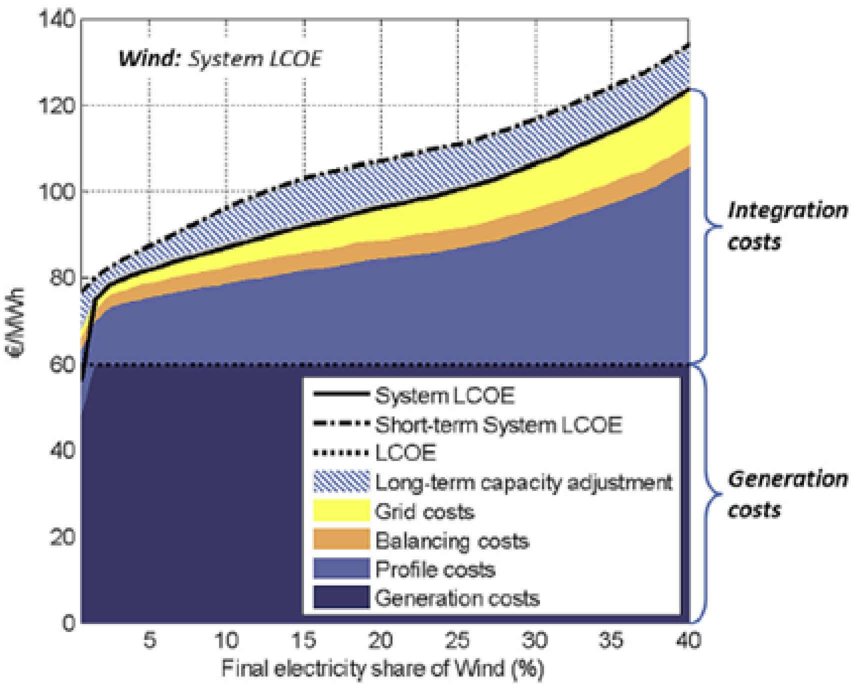
The difference between investment (LCOE) and **consumer costs** of electricity (so-called System LCOE) is growing over time. It is growing in both dimensions: as volume of RES increases and as the price of emission allowances increases. The reason is that the CO2 permit price effect is also directly reflected in the prices of grid stability services. Therefore, the price of baseload electricity may fall, but the total costs are rising, because the forced additional costs (both capital and variable) are rising faster due to the presence of two rising components. **The national economic perspective** (or social optimizer perspective) is the same as the consumer one, because it reflects the total social costs of supply (delivery) in the economy. The difference between the two approaches is in Lizal, 2025, showing LCOE is price of a commodity while consumer purchases electricity as a service.

In other words, the argument of low LCOE causing prices of the final product to decrease is the same as if the price of cheese only presents the price of milk needed for its production. No other production costs, no wages, no packaging, no transport of cheese to the store, no advertising or storage or loss of unsold expired products.

3 Regulatory market failure: the more RES, the higher the final price

The problem and its impacts are best seen on the German system, where their 12-year-old own theoretical calculations are being explicitly confirmed (Ueckerdt et al., 2013, Figure 2). Even in these calculations – and the effect was calculated with the perceived "high" allowance price of EUR 20 per ton of CO2 – the related induced costs of the grid were higher than the (direct) investment costs of RES technology (measured with LCOE) with a share of wind RES in the energy mix being of around 33 percent (which is, due to EU commitments, perceived as an unambitious mediocre goal today). And at that time, RES cost two to three times what it costs today (measured by LCOE), and the nuclear power plants were still assumed to remain in operation. However today, the price of CO2 is more than three times higher, the nuclear power plants were closed, so the induced integration costs (considered in the System LCOE) clearly dominate the investment costs (LCOE) even for lower values. Thus, the total price of electricity, which must reflect the total costs (and not only the baseload component), without doubt, cannot decrease at all.

Figure 2: Integration Costs in Germany



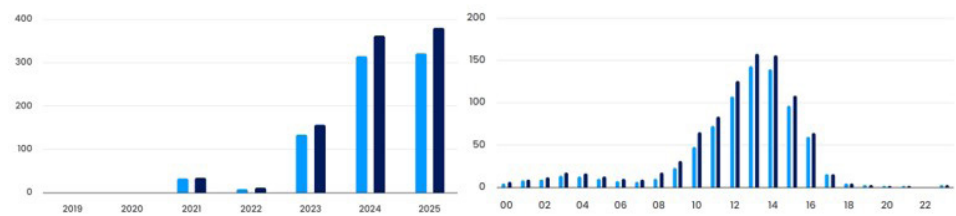
Source: Ueckert et al (2013), increasing estimated total system cost with break-even point about halfway down the graph, followed by convex curvature for a higher proportion

These unintended impacts of energy policies have started to be talked about in the European Union, but that's only because German companies have finally spoken up. And they came out because the German Constitutional Court prohibited the government from further debt, which was originally planned for further energy transition subsidies. It was only at this point that the Antwerp Declaration (2024) was created as a counterweight of industry against the loss of competitiveness due to ill-conceived energy policy. In other words, politicians got the news that ideology has definitively hit the laws of physics and people's wallets and the limits they set.

4 Cannibalization effect

The media are full of "great" news from the energy stock exchange (i.e., EEX or PXE) how much the price was negative again – that the situation is improving and electric energy prices shall eventually decrease. But what "goods" do we pay for to be removed? Waste – that's the name of the thing that someone takes over for money.

Figure 3: Negative hourly price frequency according to year and hour, respectively



Source: oenergetice.cz from ENTSO-E data, year 2025 till October. Negative prices in BLUE, negative prices including zero price in BLACK.

Negative prices (Figure 3) thus indicate not an improvement but another, **new, economic problem: cannibalization**. A situation where the overproduction of a certain technology makes it impossible to deliver return on the very investments. Investments that are still considered to be politically desirable – and further fostered with argument we have not invested enough in these. This is a new, state-invoked **regulatory-based type of market failure**. Cannibalization is also a predicted and described consequence in the above-mentioned German calculations. The social cost curve increases steeply with a higher share of uncontrollable resources - because of cannibalization (see Ueckerdt et al., 2013). The limit case, where almost all energy (95%) is provided by one type of source (so called LFSCOE, Levelized Full System Costs of Electricity), is shown in Table 1 (Idel 2022, and 2023) for two different climatic conditions. With higher share the costs of cannibalization already dominate all the other costs. The proof that this is not a theoretical problem is simple: investors today want not only investment support, but also operational support again, as the cannibalization effect is already slashing revenues.

Table 1: Comparison of LCOE and LFSOCE for Different Climatic Conditions

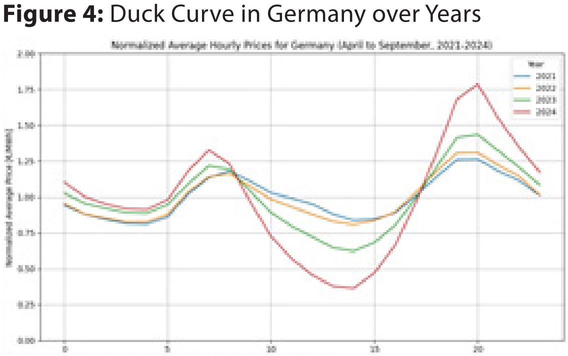
Technology	LCOE [USD/MWh]	LFSCOE Germany [USD/MWh]	LFSCOE Texas [USD/MWh]
Biomass	90	109	126
Coal (USC)	83	110	124
Natural Gas CC	40	41	46
Nuclear	88	114	134
Solar PV	36	1465	456
Wind	40	587	358

Source: Idel (2023)

The difference between the demand for baseload and balancing electricity depends largely on climatic conditions: to what extent the production of unstable RES is correlated with consumption. In Central Europe, this is clear. The highest consumption in this geographical area is in the morning and evening and in winter. These are periods that RES, and especially photovoltaics, cannot deliver. On the other hand, in California and Texas, for example, they have peaks in consumption at noon and in the evening and in summer. But even this, far more favourable geographic scenario for RES, is not resulting in a cheaper mix with the massive deployment of RES than classic emission-free sources such as nuclear.

As the seasonal cycle of the difference between production and consumption deepens with higher RES installations, this economically harmful trend will continue over time, see Figure 4.

Figure 4: Duck Curve in Germany over Years



Source: Jomaux (2025)

The increase in volatility, i.e., the so-called duck curve in Figure 4, is not without an impact on the total economic price for two reasons, again, both are contributing to price (consumer costs) increase. First, someone must pay for those negative moments (as we pay the garbage collector) and so in reality they will be reflected in additional costs (we may model it both as costs of overinvestment and costs of subsidies as well). The second factor is the excessive volatility itself. Here we can bring to our attention studies in the financial markets. Higher volatility means higher risk and thus rewards for the undertaken risk, i.e., increased price. The effect of increased volatility can be also documented with the so-called volatility tax (also volatility drag), e.g., Messmore (1995). As documented by Jacquier at al. (2003) (even with an unbiased estimator and stable distribution) the future value of an asset calculated using the arithmetic average historical return results in an upward biased and forecast obtained by using the geometric average will be downward biased. Finally, Becker (2012) was able to show the approximation (1) between arithmetic and geometric means used in empirics can be derived without distribution assumptions:

$$r_G \approx r_A - \frac{\sigma^2}{2} \qquad (1)$$

where r_A and r_G is the arithmetic average return and geometric return to the asset, respectively, and σ^2 denotes its variance. The difference between the returns based on arithmetic and geometric means is one half of the variance.

In the following calculations we will limit the scope to the direct effect of the duck curve due to price variation effect only and leave out the effect of the costs of increased volatility that should be added as pure inefficiency waste on top of our calculations should we prefer to evaluate these costs as well.

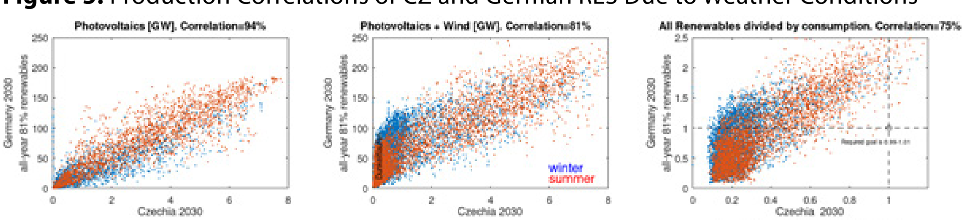
5 Model of the impact of expected energy imports on GDP in the Czech Republic

In the previous sections we have briefly described the reasons why the average yearly price cannot be used for serous modelling and is a grossly misleading simplification. In standard economics, price is determined by the nature of the goods, the place, and time of delivery. The market price changes to balance demand and supply. However, in the electricity sector the specifics of the electricity market must not be ignored or assumed out, i.e., that it cannot (yet) be (economically) stored in sufficient quantities and can only be supplied to where the distribution network allows. In addition, at a given time, production (supply) adapts to consumption (demand) at a given price. The paradigm shift from a central scheme with controllable resources to distributed production thus means a shift from the emphasis of price on its nature (commodity) to the attributes of the supply itself, i.e., **time** and **place**. Therefore, it cannot be expected that the final prices for customers will be based on the slowly falling investment costs of RES (LCOE) but will reflect the accelerating costs of the system (System LCOE), described in the section above.

In addition to the general effects above, the Czech Republic will face further challenges. Unfortunately, all of them are in favour of additional price shock in regulation energy. First, all baseline scenarios of resource adequacy (MAF CZ 2022) show an annual total deficit of 14-15GWh in 2030 and 20GWh in 2035, which is negligible. However, as shown by the modelling of Horáček and Sedmidubský (2024) and the balance heatmaps themselves in the subsequent MAF (MAF CZ 2023), **the distribution of deficits over time is heavily uneven during the year**; the domestic system shall have significant deficits in the winter and substantial export ability in the summer, similar to the situation in neighbouring countries.[2] The model thus shows that the seasonal deficit have to be compensated by an increase in **import dependence in the order of thousands of GWh** (see Appendix Table 1A). This implies further possible pressures on the price and its volatility – **exports revenue potential will be minimal in the summer, often even facing negative prices, while balancing imports will become more expensive in times of shortage, in winter, during usual *dunkelflauten* spanning with high probability** (see Figure 5) **in both Germany and Czechia and probably other neighbouring countries**. Therefore, the price estimates of the cost of import dependence in MAF CZ 2022, page 98, based on average annual prices, may be optimistically strongly skewed downwards. A realistically constructed weighted sum of the economic balance, which would respect the difference in export and import prices due to different market conditions (deficits vs. surpluses), would look significantly more pessimistic, as we will show in the simplified model later.

While the newer MAF 2023 already works with different prices during the year and different import needs during the year, the same type of problem, i.e., the application of the average annual price to different states of the grid in terms of energy availability, appears mainly in the SEEPIA models and thus the State Energy Policy (SEP). The basic problem, which SEP and SEEPIA do not consider, is **the growing divergence in both seasonal electricity prices** and the distribution of energy prices in baseload and balancing energy.[3]

Figure 5: Production Correlations of CZ and German RES Due to Weather Conditions



Notes: First graph covers PV only, middle adds wind generation, and the last one adds biomass. Own calculation using ETNSO-E data, Agora Energiewende, and https://www.electricitymaps.com/data-portal/czechia. In comparison to 2019 the Czech Republic plans to have 3.6x more installed solar and wind capacity in 2030.

2 *We provide sample of recent daily price curves in the summer and winter in the Appendix 3. While the winter curve exhibits historically common hump-shape with maximum during the day, the summer is a classical duck-shape with two maxima in the morning and evening and minimum (negative) during the daytime.*

3 *One of the most problematic aspects of both SEP and MAF 2023 lies in optimism about the availability of electricity supplies from abroad during the critical winter period. Unfortunately, there is no assessment of economic and security risks about this assumption. The theoretical sufficiency of import transmission capacities does not guarantee the availability of electricity at a reasonable price, e.g., the shortage in November 2024 with electricity prices reaching 800EUR/MWh.*

Unfortunately, the economic modelling of SEK and SEEPIA employs the annual balance only. Mathematically (and logically), the definition of a balanced electrical system is that at every moment, during each 15-minute interval, consumption must equal production (with 1% precision). This balance then directly results in the annual balance of production (plus the cross-border balance) and consumption. However, **this is an implication, not an equivalence**. Therefore, a balanced annual result does neither imply seasonal balance, nor even daily.[4]

The right part of Figure 5 is the most important as it shows that even with biomass in 2030, when the Germany claims to achieve 80% year-round coverage from RES, it will have significant surpluses and shortages at the same time as in Czech Republic

Daily balance would require huge investments into accumulation, namely a few pumped-storage dams or dozens of thousands of large battery storages and thus seasonal storage is sci-fi with today's technology. Hydrogen production has losses around ¾ in its full cycle and its transportation is challenging.

The electricity system will have significant surpluses in the summer middays (when the surrounding countries will also have surpluses and then export prices are low to zero) and deficits in the winter (when prices are higher than the annual average), see the HeatMap in MAF ČEPS (MAF CZ 2023). The difference between highs and lows has been growing over time as can be seen from Figure 4. Such a pattern is valid for German and Czech markets as well. Even though winter wind compensates for solar in summer, they are negatively correlated (they compensate) at only -21%. ENTSO/E data analysis reveals that total power of all solar plants is correlated 95% between Czechia and Germany (and similar figure would be probably for other neighbours). Including wind (that is said to be ideal complement to photovoltaic due its negative correlation), the general correlation is still 81%. All renewables (including water and biomass) are still correlated at 75%. Windless nights cover ¼ of a year in Czechia, especially in winter. This implies that surpluses of solar+wind+water electricity can hardly be sold cross borders as similar situations typically appear simultaneously on both markets (regions). Figure 5 shows these correlations of production due to weather conditions between Germany and the Czech Republic. In short, there is virtually no diversification effect in RES conditions.[5] In addition, due to the size of the German economy and its RES energy sector size, even during the uncommon situations of different weather conditions the German market would always dominate.

The situation of seasonally and continuously different prices, even with a balanced (!) annual energy balance (SEEPIA expects surpluses for exports in summer and balance

4 *The short-term hourly balance can be solved by short-term accumulation, but seasonal differences cannot be covered with direct electric accumulation. It is not yet possible to economically accumulate electricity between the seasons – that's why there are gas storage tanks for the winter to be able to increase production during this period.*

5 *The rolling blackout in Texas has been already subject to academic research, also with respect to weather conditions in neighbouring states. Wolak (2022) documents that the mechanism that was designed for a sector based on dispatch-controlled thermal generation units is inappropriate for a sector with a significant share of energy coming from intermittent renewable generation capacities.*

imports in winter) leads to a negative financial balance of foreign trade. The headline financial balance of imports due to volume imported is thus increasing with rising seasonal price differences and the surplus (deficit) in summer (winter). The increasing importance of this effect is not only seen in Figure 3 showing the increasing number of occurrences of nonpositive prices above but also is captured by the increasing volatility of the energy price.

The increasing daytime price spread from year to year is not only a problem in the EU (EMBER, 2024). It is a typical manifestation of higher volumes of PV installations, as evidenced by the increase in the likelihood of negative daytime prices AEMO (2024) in Australia suggests. Thus, one should not make an economic evaluation based on average prices (as both SEP and SEEPIA do), but it is necessary to work with variable prices during the day and seasons.[6]

As the seasonal cycle of the difference between production and consumption deepens with higher RES installations, the inevitable price differences will lead to a significant change in the financial balance of foreign trade, and thus to a further decline in GDP. The bigger the seasonal price difference the bigger the financial imbalance, ceteris paribus.

In the subsequent simplified modelling, we will show the effect of the increasing divergence of seasonal prices and daily prices on foreign trade results using the Horáček and Sedmidubský (2024) balancing energy production mix model.[7] In our calculation we will show how the change in the price of the net balance of electricity increases with increasing differences during the year and day. By augmenting the original model of physical balance with prices we will be able to model change in the trade balance and therefore in GDP. We will extend the above-mentioned model by Horáček and Sedmidubský (2024) to include an estimate of the direct change in GDP (i.e., we calculate only the initial effect without multipliers, see e.g. Jurajda et al. (2006) for the Czech Republic and Lízal (2012) directly for the analysis of the effect of emission allowances). This gives a basic estimate of the error caused using average annual prices in the SEEPIA model ignoring seasonal price differences used in SEP. We will also show a situation close to the minimum of economically feasible local coal mining and compare it to no mining (and no electricity production from brown coal) scenario, taking the capacity of coal-fired power plants in 2030 from SEP WAM3 model, i.e. 3 GW, as the limit.[8]

6 *In addition, SEEPIA scenarios work unrealistically with both the arbitrary amount of coal mined and the scalable size of nuclear power plants. However, there is a limit to the profitability of mines, i.e. from a certain level it is no longer possible to decline, but there is a step change in the closure of mines. This must always be modelled as a discontinuous transition in the model to another state with discontinuous changes.*

7 *The physical balance-production simple model of the app.energy-mix.cz is described in the Appendix 1 and with a greater detail on the public model web pages.*

8 *We provide various scenarios of production volume check in the Appendix 2. Unfortunately, these checks show unrealistic full reduction of CO_2 despite the enormous costs. Given the fact that many global firms announced cancellations, shelving, or steps back from their hydrogen plans due to surmounting costs, we doubt the speed if not feasibility of the gas-hydrogen transformation in a near future. The more stringent recent proposal of reduction of CO2 in EU by 90% by 2040 fails in the same direction.*

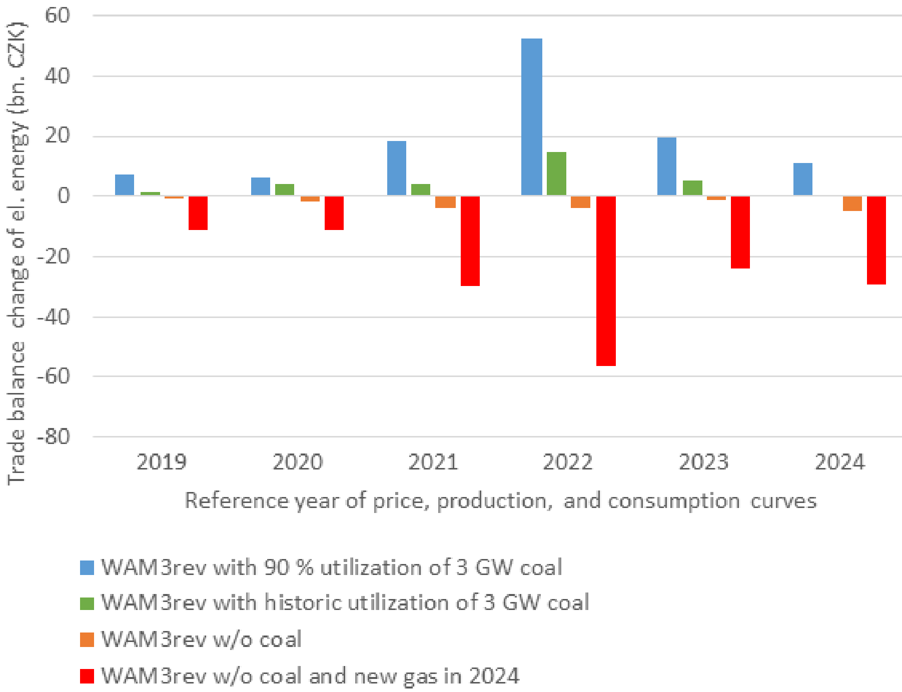
To avoid problems stemming from the inadequate future mix affecting prices in an unknown way or with a scheme driven by assumptions, we reverse the problem. Our basic idea is simple. We ask a question “What would happen in past years should the production mix be the envisaged one from the future?” We acknowledge that this is a very conservative approach, but we avoid both consumption and price prediction errors. Past values known and easily verifiable. The drawback is that we estimate the lower bound limit of the economic effect as the prices will diverge more in the future. Yet still, as we show, even the lower-bound has a size of 1% GDP yearly.

To augment the energy production mix model with economic dimension we apply prices to the *app.energy-mix.cz* production model in the WAM3 scenario as follows. To eliminate the influence of holidays and other volatile calendar influences, we calculate the average price for each hour of the day in each month. These average hourly prices that vary by each month (and thus capture both daily (hourly) and annual changes (volatility)) are then applied to the system surpluses/shortages in individual hours of the day and summarized for the whole year. We assume that the Czech Republic is a price-taker by default, i.e., regionally the Czech demand or supply will not affect the average prices achieved on the entire regional market. A surplus means exports and a positive contribution to the trade balance, a shortage of electricity is balanced with its imports and payments outwards. However, we eliminate exports at negative prices, assuming that in these situations RES are disconnected so that they do not generate further losses.[9] According to the assumption of MAF 2023, which considers a 16% yearly increase in total consumption between 2025 and 2030, we use this amount as a "target" that needs to be covered in the future production. Note that winter consumption increase will likely be even higher due to switching of coal-powered heaters towards electricity-powered heating. Indeed, coal burners consume yearly 45 000 GWh for pure heating - nearly ¾ of the Czechia 2022 electricity consumption.

We also show the sensitivity of the scenarios to different degrees of decommissioning of domestic coal-fired sources and the assumptions of their use (historical averages vs. unrealistic high availability in SEP or SEEPIA). The selected value of 3 GW (assumption of coal-fired power plant capacity in 2030 according to SEP WAM3) with high utilization undoubtedly meets the condition of the minimum necessary size of the sector, without the closure of mines due to a drop in profitability to negative values. In our results we also work both with historic (varies around 80%) or assumed high availability of production factor (set at 90%). The result is then shown in Figure 6.

9 *However, a disconnection may not be the option as any disconnection is only possible for reasons of system stability. In addition, in the case of feed-in subsidies, it pays to produce even at negative prices if the negative price (in absolute value) is lower than the guaranteed feed-in subsidy. Our simplification thus may lead to underestimation of the financial impact, i.e., we may again estimate lower bound of the impact.*

Figure 6: Models of Trade Deficit Changes with Energy Mix of 2030



Source: Authors' simulation of SEP WAM3 on the extended app.energy-mix.cz model

From the point of view of the overall change, it is necessary to note that the last scenario "without new gas" applies de facto with new gas as well, only the change in the trade deficit will not be visible in electricity column but will be reflected in a similar amount in increased gas imports. Gas imports, however, are not captured in the chart but due to the tie-up of electricity prices with gas as a result, we may rely on the fact that gas sources are the "closing merit order" production facilities at the instance of scarcity. Thus, the last column in Figure 6 is also sufficient for the first rough approximation of the same total fiscal effect with new gas imports. In terms of financial impact, the decreases in imports of electric energy due to the substitution of increased gas imports for electricity productions are equivalent.

These two sub-scenarios are therefore actually financially similar in terms of the overall impacts on the change in the GDP trade balance, and de facto the last, red column applies; just one can note that with new gas power plants the system has a better position in terms of domestic regulatory potential (so will not have to import balancing electricity as well).

In sum, as the nominal GDP in the year 2022 and 2023 was 7000 and 7600 bn CZK, respectively, the primary effect being change about 40-50 bn CZK represent change in GDP between 0.5% - 0.7%. With Czech fiscal multipliers being estimated around 0.5-0.6 (e.g., claim of Klyuev and Snudden, 2011, on CNB models) we get the total impact being between 0.75% and 1.12%, each year.

Conclusion

The development of the energy sector is and will be driven by the (state) regulatory interventions. Unfortunately, these are often reactive, i.e., they react only to an already existing problem and are not introduced proactively to prevent forthcoming issues.

Developments in the energy sector will thus continue to be determined only by political decisions, and fundamental changes can therefore only be expected either within the election cycle (after the elections) or as a response to an acute crisis (e.g., the recent blackouts).

In a simplified model, we have shown that the results of the current economic and energy policy lead to a situation where the Czech Republic will be significantly dependent on the external environment and spend dozens of billions on electricity imports (just as we spend on oil, for example), which is a net loss in terms of GDP, and behaves like energy tax levied on the whole economy. In fact, the development aims against the original philosophy of energy transition, which had the primary goal of reducing energy import dependence. Unfortunately, this is the most likely scenario, as we have been moving towards it for several years by gravity. Our simple model estimates the effect of around 1% of GDP, annually.

The negative impact on GDP and the increase in energy prices for end customers brings up the question of adequacy and social sustainability of the whole concept. A necessary condition for maintaining social justice and the financial stability of the system is electric distribution tariff reform (Lízal, 2024). However, its inevitable aspect (in addition to resolving the current anti-social redistributive character towards those who cannot enjoy the benefits of their own domestic PV plants) must also be an element that significantly penalizes deviations of customers or producers (e.g., the use of the so-called G-component). Only such an approach can allow us to pass on the rising costs of the deviation to its originators more fairly. However, from the customer's point of view, the result will be a decrease in customer comfort and an increase in the final price for the self-producers. These recommendations are in line with findings of Wiser et al. (2025) who found evidence using USA data that states with the greatest price decreases typically exhibited increasing customer loads while behind-the-meter solar standards increased prices.

However, the above outlined options and scenarios have unpleasant political and economic costs that cannot be avoided. So far, the passive approach of postponing the solution of the problem carries the risks of significant (electric) energy import dependence and social impacts and increases the distortions as well as incumbent pressures to stop any reform. Changing the trend and revision of the State Energy Policy requires fundamental strategic policy decisions.

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Annex 1: APP-ENERGYMIX – Description of The Energy Production Balance

The hourly production and consumption data used in this model comes from a public source, ENTSO-E as well as data on installed capacities in historical years. A following definition of the electricity production and consumption curve used in the https://app.energy-mix.cz model:

- Hourly production curves represent the so-called net production of electrical sources.

- The hourly consumption curve represents the consumption of the Czech Republic, including total losses, i.e. losses in the transmission system and distribution systems.

Model Assumptions and Limitations

The app.energy-mix.cz model is based on assumptions that allow us to test the self-sufficiency of any electricity mix in the Czech Republic. Since electricity shortages and surpluses occur mainly in different seasons, they do not compensate for each other. The grain size of the model is hourly. The following assumptions are "optimistic" – they underestimate the resulting shortcomings of electricity, which makes this model conservative. The real shortage of electricity therefore will be worse than the simulation suggests.

Technical Assumptions

- Ideal transmission network without loss,

- immediate start-up of gas sources and unlimited gas supply,

- no extraordinary outages of the sources, sources copy the outages in the selected reference year,

- analogously to the MAF assumptions of growing demand the annual electricity consumption is assumed to be increased (but conservatively) to 70 700 GWh in 2030,

- the consumption curve defined in this way does not include the expected relative increase in winter electricity consumption due to the gradual transition of heating to heat pumps.

Control algorithm

In the control algorithm, the so-called scaled and partially controlled sources are always connected to the power grid as a priority. Scaled sources include nuclear, hydroelectric power plants (except pumped storage), biomass + other RES. The only partially controlled source is coal, for which the scaling of the historical production curve is supplemented by an adjustable coefficient of annual utilization. The continuous lack of electricity after the connection of these sources is compensated for by so-called controlled sources, i.e., first by accumulation and then by gas. The ongoing surplus electricity is then used to charge storage capacities and export. The storage source represents the storage capacity of the Czech Republic with a charging and discharging cycle efficiency of 90%. It combines pumped-storage hydroelectric power plants and battery systems into one modelled source.

Coal-fired power plants and scaled sources

In the modelled scenario "WAM3rev with historical use of 3 GW of coal", the coal source behaves in the same way as other so-called scaled sources. This means that the electricity production curve is rescaled by a multiplying factor so that the set installed capacity of the source is a corresponding multiple of the installed capacity in the reference year. This scaling principle is also applied, for example, to the production curves of RES. In the scenario "WAM3rev with 90% use of 3 GW of coal" the coal production curve is transformed so that the resulting coefficient of annual utilization (average output of the source) is 90%. This corresponds to about 95% of average winter utilization and 85% in the summer.

Accumulation

Storage sources are charged only during periods of surplus electricity, with a maximum charging capacity of 2172 MW up to a maximum capacity of 7500 MWh. Discharging occurs only during periods of continuous shortage of electricity from priority sources, with a maximum discharge capacity of 2172 MW. When an electricity shortage occurs, the algorithm first evaluates the duration of the shortage period. If it lasts less than 24 hours, the initial available accumulated capacity is allocated evenly to the shortage period. In the case of a duration of more than 24 hours, the initial accumulated capacity shall be allocated evenly over the following 24 hours. The discharge power for each hour of the shortage period is then given as the minimum of the allocated energy for the given hour, the power needed to make up for the current consumption and the maximum discharge power.

Gas-fired power plants

In the event of a shortage of electricity even after the connection of storage capacities, gas-fired power plants are connected (all types combined into one category). For simplicity, we consider the possibility of immediate start-up up to the installed capacity, assuming unlimited gas availability and zero failure rate of the source. The algorithm tries to match the current electricity consumption and is limited only by the installed capacity. It is not used to generate excess electricity.

Limitations and Bias

In winter, the real consumption curve is therefore likely to be higher than assumed by the model. For these reasons, the estimated deficits are optimistic, i.e. smaller than what would result from a fully incorporated transition to heat pumps. In sum, for economic evaluation the model provides better (ideal) outcomes of energy balance and therefore the real economic impact would be higher due to inefficiencies and other mismatches neglected. This is in line with the rest of methodology that also focuses on lower-bound of the economic effect estimate.

Annex 2: APP-ENERGYMIX – Scenarios Balance Verification

Table A1: Long-term general verification of SEP WAM3:

Energy mix	Consumption as % of 2019	Gas		Accumulation		Solar	Wind	Biomass	Hydro	Coal		Nuclear	Invest. estimate [bn. CZK]	Produced $CO_{2,eq}$ [Mt]	Gross total electricity deficit [TWh]	Peak electricity deficit [GW]	Net total electricity surplus [TWh]
		Installed power [GWp]	Imported [TWh]	kapacity [GWh]	Installed power [GWp]	Installed power [GWp]	Installed power [GWp]	Installed power [GWp]	Installed power [GWp]	Installed power [GWp]	average power utilization	Installed power [GWp]					
Reference year 2019	100%	1,23	5,4	5	1,175	2,05	0,32	0,90	1,09	10	40%	4,04	0	43 +/- 2	0,00	0,0	16,1
WAM3 scenario 2025	100%	1,23	5,4	5	1,175	3,10	0,32	0,90	1,09	6	40%	4,28	61	27 +/- 2	0,49	1,8	0,9
WAM3 scenario 2025 coal 65 % average power utilisation	100%	1,23	5,4	5	1,175	3,10	0,32	0,90	1,09	6	65%	4,28	61	38 +/- 2	0,00	0,2	9,8
WAM3 scenario 2030 (SEP) BASELINE ECONOMIC MODEL INPUT	110%	3,20	13,0	5	1,175	10,10	1,50	0,90	1,09	3	40%	4,04	313	22 +/- 3	0,50	2,4	1,5
WAM3 scenario 2030 self-sufficient	110%	5,60	13,5	5	1,175	10,10	1,50	0,90	1,09	3	40%	4,04	378	23 +/- 3	0,00	0,0	1,5
WAM3 scenario 2030 coal 80 % average power utilisation	110%	3,20	5,4	5	1,175	10,10	1,50	0,90	1,09	3	80%	4,04	313	28 +/- 2	0,05	1,2	3,9
WAM3 scenario 2033	110%	3,20	19,8	5	1,175	10,10	1,50	0,90	1,09	0	0%	4,04	313	15 +/- 5	3,39	3,8	0,6
WAM3 scenario 2050	170%	4,00	23,1	5	1,175	26,10	5,50	0,90	1,09	0	0%	5,90	1 224	19 +/- 6	7,53	7,3	7,8
WAM3 scenario 2050 +4x500 MW nuclear reactors	170%	4,00	15,6	10	2,344	26,10	5,50	0,90	1,09	0	0%	8,00	1 597	17 +/- 5	2,38	5,4	9,8
WAM3 scenario 2050 self-sufficient	170%	11,30	30,6	5	1,175	26,10	5,50	0,90	1,09	0	0%	5,90	1421	24 +/- 7	0,00	0,0	7,8

Table A2: Short-term verification subset used in economic model

Energy mix sensitivity analysis for WAM3 at 2030	Consumption as % of 2019	Gas		Accumulation		Solar	Wind	Biomass	Hydro	Coal		Nuclear	Invest. estimate [bn. CZK]	Produced $CO_{2,eq}$ [Mt]	Total electricity gap [TWh]	Peak electricity deficit [GW]	time of required el. import > 2.5 GW [h]
		installed power [GWp]	imported [TWh]	kapacity [GWh]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	installed power [GWp]	average power utilization	installed power [GWp]					
Reference year 2019	100%	1,23	5,4	5	1,175	2,05	0,32	0,90	1,09	10	40%	4,04	0	43 +/- 2	0,0	0,0	0,0
WAM3 scenario 2030	110%	3,63	2,2	5	1,175	10,05	1,44	1,42	1,09	3	95%	4,04	61	30 +/- 2	0,0	0,1	0,0
WAM3 scenario 2030 coal 0 %	110%	3,63	18,7	5	1,175	10,05	1,44	1,42	1,09	0	0%	4,04	61	14 +/- 4	1,4	3,0	35,0
WAM3 scenario 2030 coal 0 %, gas 50 %	110%	2,40	15,2	5	1,175	10,05	1,44	1,42	1,09	0	0%	4,04	313	12 +/- 4	5,0	4,3	424,0
WAM3 scenario 2030 coal 0 %, gas 50 % and renewables	110%	2,40	18,2	5	1,175	6,05	0,89	1,42	1,09	0	0%	4,04	378	14 +/- 4	6,9	4,3	588,0
WAM3 scenario 2030 coal 0 %, gas 50 % and renewables 1 nuclear reactor Temelin offline	110%	2,40	20,0	5	1,175	6,05	0,89	1,42	1,09	0	0%	2,95	313	14 +/- 5	12,8	5,3	1 698,0

Notes: Authors app.energy-mix.cz simulations, the colours denote the approximate degree of "problems" expected, green being the least problematic over yellow and orange to red that represents the most severe case. Due to different base of MAF 2023 the model final consumption increase corresponds to it.

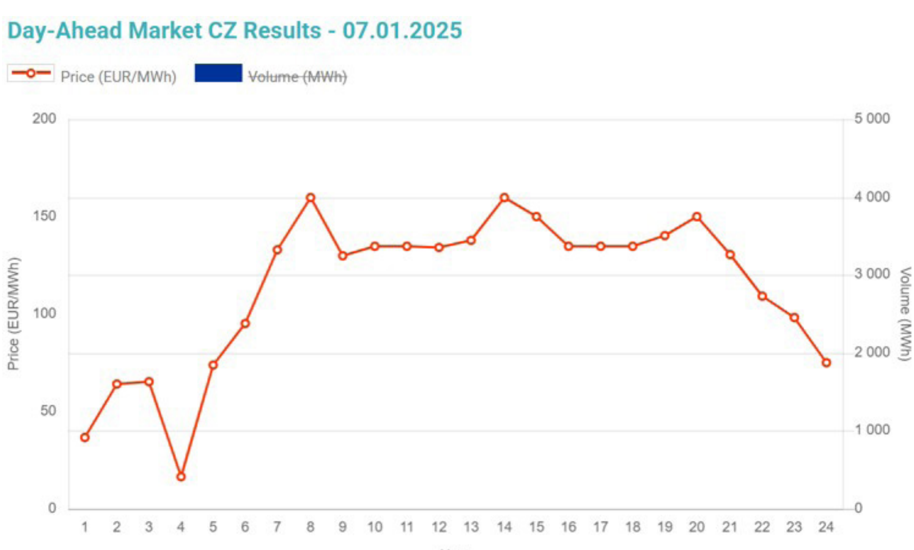
The various scenarios are verified using physical balance. For the subsequent economic modelling any excess of production can be exported, and any energy deficit can be covered using imports. The balance modelling shows increasing import dependency despite rising capacity investment costs. The models also show increasing seasonal patterns with growing surpluses in summer and increasing deficits in winter.

Sources: own app.energy-mix.cz simulations

Annex 3: Typical Summer and Winter Price Movements

Figure A1: Summer prices – typical example

Figure A2: Winter prices – typical example



Data is from OTE database: https://www.ote-cr.cz/en/short-term-markets/electricity/day-ahead-market?date=2025-05 for summer and for winter https://www.ote-cr.cz/en/short-term-markets/electricity/day-ahead-market?date=2025-01-07, trading volumes excluded from the graph for clarity, but all were above 2000MWh.

Modeling of Monetary Financial Flows in System Dynamics

PAVEL BYKOV

Abstract

Background: The relationship between public debt and private sector profitability has long been emphasized in economic theory in the context of sectoral balances. According to Post-Keynesian economics, private debt accumulation, under certain conditions, may be a source of private sector profits. Moreover, public debt dynamics may have a strong relationship to the evolution of firms' sector debt.

Aim: This paper develops a monetary financial model of a small open economy using the stock-flow consistent and system dynamics frameworks, focusing on the interplay between the public and the private sector debts, and public debt and private sector profitability. The aim is to test – using the model – the hypothesis that public debt as an injection of net financial assets into the economy may positively influence private sector profits. Additionally, the model assesses the relationship between the public debt and the firms' debt sector dynamics.

Methodology: Stock-flow consistent approach together with nonlinear differential equations and non-equilibrium approach are used to build the model. System dynamics is used for model simulations. The model works with quarterly time periods, six sectors – central bank, government, banks, households, firms and the rest of the world, consolidated sector balance sheet items acting as stocks, and inflows and outflows changing the value of those items - as flows. Behavioral equations define the model behavior, and interest rate mechanism is used as the global feedback loop. The model tracks how monetary flows across consolidated sectors change the accumulation of stocks and a variety of real and nominal macroeconomic variables. Baseline, boom and negative shock scenarios are used to simulate the outcome of the model on simulated data.

Results: According to the simulation results, public debt accumulation may contribute to private sector profitability. Public debt may also have an inverse relationship with the dynamics of firms' sector debt. However, the introduction of export shocks can trigger a systemic decline. The model highlights a strong link between public debt and private sector debt dynamics, as well as high sensitivity of real macroeconomic variables to external flows for a small open economy.

Recommendations: This paper underscores critical influence of the foreign sector, policy rule design and endogenous debt dynamics across different sectors on a small open economy and variety of its macroeconomic variables. Although it is highly recommended to apply SFC framework and system dynamics with a high level of parametrization and a variety of feedback loops – the model provides valuable insights into the discussions of public debt evolution and its implications.

Relevance: This paper addresses a key topic in practical economic policy: the dynamics of public debt, its potential drivers and causes. It develops a mathematical model based on complex nonlinear relationships with a useful simulation framework. This framework might help economists and policymakers better understand the causes, implications, and intersectoral relationships associated with the public debt.

Originality: This paper is original, based on the ideas of Wynn Godley, Randall Wray, Steve Keen, Marc Lavoie and Thomas Palley, providing an originally developed consolidated balance sheet of foreign sector (rest of the world), and dynamic interest rate and inflation mechanisms. Additionally, original dependencies are introduced to the model – banks' CAR ratio, advanced interest rate feedback loop mechanism and advanced logic of sectoral flows.

Keywords
stock flow consistent modeling, system dynamics, public debt, monetary economics

JEL Codes
~~R31, O18, F35, H56~~

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Introduction

The relationship between public and private debts, and between public debt and private sector profits, has long been a widely studied area in Post-Keynesian economics. Early thinkers, namely Michal Kalecki (1954) and Hyman Minsky (1986), opposed orthodox views that described government deficits as burdens,[1] and argued that public deficits instead inject net financial assets into the private sector, thereby supporting demand and boosting private sector profits. Following the development of input-output analysis (Leontief, 1966) the concept that government deficits might generate net financial assets for the private sector gained greater prominence in Post-Keynesian economics and was formalized into a hypothesis stating that government deficits correspond to equivalent private sector surpluses. Recent studies by Steve Keen (2011) and Stephanie Kelton (2020) argue that fiscal deficits are instrumental in enabling the private sector to accumulate wealth.

This paper examines the debate on public deficits and private sector profits, introducing a monetary model to test the hypothesis that public deficits might causally lead to

1 *Formal interpretation of the SFC framework was provided by Lavoie (2014)*

accumulation of private sector profits. The model also examines the relationship between private and public debt dynamics. We develop a model of a small open economy using the consistent stock-flow (SFC) framework, as defined by Godley and Lavoie (2007). The SFC model defines monetary sectors – in our model central bank, banks, households, government, firms and foreign sector, represented by stocks - aggregated balance sheet items categorized as financial assets or liabilities, and stocks - categorized as inflows our outflows, changing the value of those stocks. Model ensures accounting continuity through the zero-sum rule, thus:

$$\sum_{s=1}^{n} Bj, s = 0 \quad \forall_j$$

Where $\Sigma^{n}_{s=1}$ *Bj*, *s* is the sum of all holdings of instrument *j* by sector *s*. This principle reflects the rule that a holding is recorded as positive when it constitutes an asset and negative when it represents a liability, with each sector's asset corresponding to another sector's liability, thus preserving balanced sectoral accounts.

First, we define all balance sheet items - stocks and flows - for consolidated balance sheets of all the sectors. Secondly, we define the relationships and logic of incoming and outgoing flows. Thirdly, we set and calibrate model parameters using approximate simulated data to reflect the reality of a small open economy. Finally, we run simulations of the model under different conditions and introduce shocks to assess the model's behavior. The model is tested in simulations with given time periods of 33 to 42 quarters,[2] with various parameter settings, reflecting conditions of different phases of economic cycles - baseline scenario with the modest growth, and shock scenarios with positive and negative shocks.

The simulations reveal several robust patterns across all three scenarios. In the baseline, stable exports and moderate fiscal deficits may support the accumulation of firms' net financial assets while keeping private debt contained. Government and firms' net financial positions move inversely, suggesting a possible substitution between public deficits and private borrowing.

This relationship persists in the boom scenario, where stronger external demand raises GDP, wages, money supply, and firms' profits, improving private-sector balance sheets. In the negative-shock scenario, a decline in exports and reduced fiscal injections coincide with falling GDP, wages, firms' net financial assets, and private borrowing. Inflation and interest rates adjust consistently to changes in the output gap across all simulations.

Overall, the results indicate that the hypothesized link between public debt and private-sector financial results might hold, but is highly sensitive to foreign-sector conditions and definitions of behavioral equations. For small open economies, even modest external shocks can significantly reshape balance sheet dynamics, underscoring the need for empirical validation and more detailed modelling of foreign flows.

2 *Ravel uses Runge-Kutta 4 (RK-4) as a numerical solver for the differential equations. Thus the number of simulated time periods may vary depending on every simulation. For the details, see Devries, 2011.*

Literature review

Normative studies and research on the link between public debt and private-sector profits could be rooted almost a century back and can be organized into complementary categories.

Historically, early Keynesian and Post-Keynesian theorists recognized that fiscal policy influences private income and profit dynamics. Kalecki's Theory of Economic Dynamics (1954) formalized the idea that public deficits stimulate the profits necessary for capital reproduction, while Minsky's Financial Instability Theory (1986) highlighted the stabilizing role of fiscal deficits in phases of private deleveraging. The idea of net financial assets injection into the economy was later formalized by endogenous money creation theory (Moore, 1988), which was effectively confirmed by Bank of England (2014) and Bundesbank (2017). Even earlier theorists like Wicksell and Schumpeter began to articulate how credit creation and monetary dynamics might influence private sector financial accumulation, yet they lacked the accounting-based formalism to track sectoral balances precisely. Schumpeter (1934) introduced the idea of credit-fueled innovation cycles, which influenced a number of later Keynesian and Post-Keynesian economists (e.g., Freeman, 2001) in analyzing long-term economic transformations based on cycles.

However, early *attempts to formalize* the relationship between fiscal deficits dynamics and private sector profitability using a comprehensive frame were largely descriptive. Leontief's (1966) input-output framework provided a significant empirical step by introducing consistent inter-sectoral accounting, but it lacked dynamic feedback mechanisms and non-linear relationships. Goodwin (1967) introduced cyclical modeling with endogenous systemic variables such as wages and profits, but without the explicit integration of fiscal policy variables. Wynn Godley and Mark Lavoie (2007) introduced a stock-flow consistent (SFC) model, embedding double-entry accounting foundations in macro modelling. Further contributions extended the approach - Dos Santos (2004) integrated bank behavior, while Lavoie (2014) surveyed Post-Keynesian monetary theory. Wray (2015) linked modern monetary theory (MMT) to SFC framework, while Pierros (2024) recently provided empirical support for SFC modelling with critical analysis on complexity of the models. Meijers, Muysken & Piccillo (2023) demonstrated the framework's flexibility for combining SFC and theory of expectations.

In order to properly implement stock-flow consistent models, a strong and flexible simulation environment is required. One such environment is provided by the *system dynamics (SD) framework*. Originating with Jay W. Forrester's pioneering work (1961), system dynamics was initially developed to model complex industrial and managerial processes using differential equations and causal feedback loops. Its extension to macroeconomics gained traction with study by Meadows et al. (1972), followed by economic-specific applications in the work of Alfeld and Graham (1976) and Richardson (1995), who showed how SD could model cyclical instability, policy feedback, and long-term structural behavior. Sterman (2000) further formalized SD modeling principles in economics through his comprehensive framework for policy design and simulation.

Radzicki (2020) expanded on his ideas with a meta overview on system dynamics modeling monetary and macroeconomic flows.

More recently, Steve Keen introduced the use of SD software platforms - first Minsky and now Ravel - to track monetary and fiscal flows in real time, preserving accounting identities while capturing non-linear dynamic feedback. Keen (2011, 2023) argues that sustained fiscal deficits offset the profit-squeezing effects of private debt service and prevent debt-deflation dynamics.[3] Kelton (2020) popularized the same mechanism in the public discourse, arguing for government deficits as the private sector's net financial assets. SFC modelling applications, such as Gräbner-Radkowitsch, Heimberger, Kapeller, Landesmann, and Schütz (2022) and Gallo and Serra (2024), demonstrated valid approaches while developing frameworks to analyze internal macroeconomic imbalances and cyclical dynamics, including investment-driven boom-bust patterns and financial fragility within integrated monetary systems. Berr & Monvoison (2023) integrated the fundamental ideas of monetary circuit theory (MCT)[4] into the SFC framework. Additionally, some recent studies (see Nishi & Okuma, 2024) underline the role of debt accumulation in support of the Post-Keynesian concept. On a critical note, a number of studies were recently published criticizing the complexity of SFC models (e.g., see Asensio, 2019).

Despite this criticism, recent literature highlights the growing relevance of stock-flow consistent (SFC) models across macroeconomic fields. Carnevali (2021) proposes a simplified open economy framework, Carnevali et al. (2023) integrates ecological and social aspects, and Vianna (2024) applies an agent based (AB) SFC model to income distribution. These studies demonstrate the models' versatility and expanding use.

Methodology

Although existing methodologies on SFC modelling with system dynamics are less frequent, we follow a simple step-by-step logic of SFC model creation, calibration and testing, partly using methodological blocks used by Bank of England (2016) and Gennarro Zezza (2020).

Basic accounting continuity rule ensures that for every balance sheet, represented by assets(A), liabilities(L) and equity(E) the following is valid:

$$A = L + E \rightarrow A - L - E = 0$$

In our case, the balance sheet represents consolidated financial items of the chosen sector. Each sector is modelled with defined stocks and flows. Stocks are balance sheet items, distinguished by assets, liabilities or financial equity - net financial assets, flows are specific accounting operations that change the value of those items. First, we define all core stocks and flows in our model.

3 *Keen directly addresses Fishers' debt deflation theory in chapter two of his manifesto (for details see Keen, 2021).*

4 *For detail see Parguez and Seccareccia (2000).*

Second, we define a set of behavioral equations for the flows. Those are partially simply derived from stocks using a variable and multiplication operator, and partially - using normative equations, e.g., Taylor rules or inflation gaps. Behavioral equations govern spending, investment, credit, borrowing and taxation.

Thirdly, we construct new aggregated flows, which are not part of the core flows, meaning that they are not accounting operations, changing the stocks, but rather an aggregated values, e.g. GDP, output gap or total loans which are necessary and helpful for accomplishing the final version of the model.

Fourthly, we introduce a global feedback loop. It is represented by the dynamic interest rate, consisting of the base market rate, central bank rate and a set of sensitivity parameters. On top of interest rates, inflation, inflation gap and output gap act as further variables, affecting interest rates and households spending. Interest rates and inflation adjust dynamically, following a simple Phillips-curve rule - it rises with a positive output gap and falls with a negative one - while the policy rate obeys a Taylor-type rule that adjusts each simulated period to deviations of inflation and output from their steady-state targets.

Finally, we run simulations. Simulations cover 33 to 42 quarter periods and include baseline and positive/negative shock scenarios. Ravel's charting and data import tools are used for analysis.

Building the model - defining stocks and flows

First, we need to define all stocks and flows in our model. As we are building a monetary model focused mostly on the endogenous monetary flows, only liabilities of the central bank are represented in the model. The asset side of the central bank is nominally represented by the foreign currency reserves; however, no operations are modeled there. It is important to underline that sterilized foreign currency operations by the central bank have limited to no effect on short-term money market interest rates. Important operations are conducted on the liabilities side. Liabilities are defined by two stocks. Commercial bank balances at the central bank (R), and government balances at central bank (H_G). Reserves increase, when government pays interest rate on government bonds to commercial banks or non-banking sector (Φ_B), and when the government spends (G). Conversingly, reserve balances decrease when the government taxes (T), and when the government sells government bonds (ΔB). Thus, dynamic change of R stock is defined:

$$\frac{dR}{dt} = G + \phi B - (T + \Delta B)$$

H_G stock is dynamically defined by similar flows with the opposite order.

$$\frac{dH_G}{dt} = T + \Delta B - (G + \phi B)$$

Other items, e.g., central bank spending, is not considered in this model.

Next, we define stocks and flows for the government sector. Assets are represented by R, liabilities (LI_G) are solely represented by the government bonds (B). Net financial assets(G_E) are represented by τY, G and ΦB , and are defined:

$$\frac{dG_E}{dt} = T - (\phi B - G)$$

Next, we define the stocks and flows for the household sector. In our model, banks provide loans to both the firms and the households, so assets, liabilities and net financial assets are presented in the model. Assets are defined by a single stock (H_H). It increases when the firms pay wages to the households (W) and when households borrow (ΔLhh), and decreases when households consume (C) pay taxes, repay the principle of the loans to the banks (R_{HH}), pay interest from the loans to the banks (ΦL_{HH}) and directly pay for the imported goods or services (M_{HH}). Households stock is thus dynamically defined:

$$\frac{dH_H}{dt} = \Delta L_{hh} + W - (R_{HH} + C + T + \phi L_{HH} + M_{HH})$$

Liabilities of the household's sector (LI_{HH}) increase with ΔL_{hh} and decrease with R_{HH}. Households' net financial assets (HH_E) are dynamically defined:

$$\frac{dHH_E}{dt} = W - (C + T + \phi L_{HH} + M_{HH})$$

Next, we define the stocks and flows for the firms 'sector. Assets are represented by a single flow (H_F). It increases when banks give new loans to the firms (ΔL_f), when households consume, when the government spends, when banks buy services from the firms (C_B) and when the firms export (M_F). H_F decreases, when firms pay wages to households, when firms pay interest to the banks on bank loans (ΦL_F), when firms pay dividends to foreign shareholders (D_F), when firms repay the principle of the loans (R_F), and when firms directly pay for imported goods and services (M_{Fimp}). Thus, dynamic changes of H_F stock are given by:

$$\frac{dH_F}{dt} = \Delta L_f + C + \mathrm{G} + C_B + M_F - \left(R_F + W + F_E + D_F + M_{F_{imp}}\right)$$

Liabilities of the firm's sector (Λ_F) are solely represented by the firm's debt position towards the banks – loans and loan repayments. Net financial assets of the firm's sector (F_E) are defined by the same items and the same order, less L_f and R_F, thus:

$$\frac{dF_E}{dt} = C + \mathrm{G} + C_B + M_F - \left(W + F_E + \phi L_F + D_F + M_{F_{imp}}\right)$$

Next, we define stocks and flows for the foreign sector. Assets are defined by a single stock (H_{ROW}). H_{ROW} increases with M_{Fimp}, D_F, when the banks pay dividends to its foreign shareholders (D_B), and with M_{HH} . H_{ROW} decreases with M_F . H_{ROW} is therefore dynamically defined:

$$\frac{dH_{ROW}}{dt} = M_{F_{imp}} + D_F + D_B + M_{HH} - M_F$$

Net financial assets (E_{ROW}) are dynamically defined by similar items.

Finally, we define stocks and flows for the banking sector. Assets are defined by four stocks - R, Λ_F, LI_{HH}, LI_G and *Nostro-accounts* - banks' sector claims towards the rest of the world (H_{BROW}) . H_{BROW} increases with M_F and decreases with D_F , D_B , M_{Fimp} and M_{HH}. Thus, H_{BROW} is dynamically defined:

$$\frac{dH_{B_{ROW}}}{dt} = M_F - (M_F + D_F + D_B + M_{HH})$$

Liabilities of the banking sector (LI_B) are defined by H_{HH} and H_F. Net financial assets of the banking sector are (B_E) increase with ΦL_F and ΦL_{HH}, and decrease with C_B and D_B.

Full list of stocks and flows of are listed in Table 1.

Building the model – defining logic of the flows

Next, after all stocks and flows are defined, we need to implement specific logic of flows. Defining complex monetary relations in the economy is a complex task, which requires application of both the assumptions of normative economy and simplifications. From existing stocks and flows we need to derive the major real economic variable – gross domestic product. This could be done as turnover of the asset side of the firms' sector[5] – H_F - divided by a ratio, which we define as V_F, thus:

$$GDP = \frac{H_F}{V_F}$$

Similarly, we can now derive W as a simple portion of GDP, by introducing another ratio, which we define as W_s. Now:

$$W = W_s * GDP$$

Similarly, level of spending of the government per time period could be simply defined proportionally to GDP by introducing a ratio defined as g_s. Now our flow G is defined:

$$G = g_s * GDP$$

5 *This logic is rooted in the classical quantity-theory of money, where monetary velocity links money balances to the volume of production and output. Post-Keynesian, marxian, and also modern mainstream "production-side" approaches similarly treat GDP as a monetary expression of the turnover of firms' assets generated through production, e.g. SNA, 2009.*

By introducing the tax rate parameter (τ), we can similarly derive the tax rate and define the level of taxation in the economy by multiplying GDP by this new ratio,[6] thus:

$$T = GDP * \tau$$

The feedback-loop mechanism of the whole model is the interest rate. Its definition combines both exogenous policy input and endogenous market adjustments. First, we specify an exogenous central bank policy rate (r^{CB}). The effective interest rate (r) is then determined as the sum of this policy rate and the endogenous market-rate component r_{market}:

$$r = r^{CB} + r_{market}$$

The market interest rate itself emerges from a nonlinear reaction mechanism. It responds to three key macro-financial gaps: the inflation gap, the output gap, and the Taylor gap. r_{market} is a function of the deviation of inflation from its steady state, the deviation of output from its potential level, and the calibrated sensitivity parameters.

We also add a second layer of endogeneity: the determination of loan rates through the interaction between firms' loan demand and banks' loan supply. ΔL_f is generated as the outcome of two competing flows – firms' demand on loans (DL_F) and banks' supply of loans (SL_B) - both of which react to the current interest-rate environment and to the evolving macroeconomic gaps.

The total borrowing flow for the firm's sector is therefore defined as:

$$\Delta L_f = min\ (DL_F, SL_B)$$

Defining SL_B – maximum loans that banks can give at a given period of time could be simplified to B_E multiplied by a leverage ratio, which we define as Lev_r, simply in general mirroring CAR[7] thus:

$$SL_B = B_E * Lev_r$$

However, defining DL_F requires adding more new ratios. Here we simply define the willingness of the firms to borrow by two exogenous ratios. We define the first one as β^{max} and second as β_S. By calibrating those two ratios we can always define firms demand for borrowing, which is then given by:

$$DL_F = H_F * (\beta^{max} - \beta_S * r)$$

6 *Tax rate is considered as the weighted average of firms' sector and households – W and T.*

7 *As we are building the financial model, every asset item on the banks' balance sheet is risk weighted.*

Now after defining borrow and lend offers; by introducing the flow of total interest paid by the firms (I_F), we can simply define the interest rates paid by the firms to the banks.

$$I_F = r * \Delta L_f$$

We further introduce an exogenous sensitivity parameter, denoted as κ_r, capturing how strongly the market interest rate reacts to imbalances in credit conditions. The instantaneous change in the market interest rate (Δr) is defined as the difference between the total borrowing offer and the total lending offer, adjusted for bond issuance, multiplied by the sensitivity parameter and normalized by GDP:

$$\Delta r = \frac{(DL_F + SL_B - \Delta B) * \beta_S}{GDP}$$

Growth in the model is generated directly from credit dynamics. The actual growth rate (GR) is defined as the ratio of net new loans to the firms' and households' balance-sheet position. Net new loans equal the total borrowing of firms and households minus their respective repayments, and this net credit flow is normalized by the stock of firms' assets:

$$GR = \frac{\Delta L_f + \Delta L_{hh} - R_F - R_{HH}}{H_F}$$

The steady-state growth rate (GR_{ss}) is introduced exogenously as the long-run balanced-growth benchmark. The output gap is then defined as the deviation of actual growth from this benchmark:

$$Out_{GAP} = GR - GR_{ss}$$

Inflation is generated endogenously from this cyclical imbalance. The model defines the inflation rate (π) as the targeted inflation rate (π_{ss}) plus the output gap scaled by the price-sensitivity parameter Φ_p:

$$\pi = \pi_{ss} + \Phi_p * Out_{GAP}$$

The deviation of inflation from its target produces an inflation gap:

$$\pi_{GAP} = \pi - \pi_{ss}$$

Finally, the Taylor gap aggregates the inflation gap and the output gap into a single reaction term for the interest rate mechanism. Using the parameters a_p and a_y, which represent the central bank's sensitivity to inflation and real-activity deviations, the Taylor gap is defined as:

$$Out_{GAP} = a_p * \pi_{GAP} + a_y * Out_{GAP}$$

r_{market} is therefore the feedback loop mechanism, driving the whole model.

Now, once we have the market interest rate and inflation, alongside additional variables and flows, fully defined, we can define the total amount of interest paid by the government (I_G) and the households (I_{hh}):

$$I_G = LI_G * r$$

$$I_{hh} = LI_{HH} * r$$

Household consumption is driven by an inflation-adjusted spending rate. The model first defines a baseline household spend rate (S_{hh}). This baseline is then modified by the inflation gap to obtain the effective spending rate (S_{hh}^{eff}):

$$S_{hh}^{eff} = S_{hh} * (1 + \lambda_{inf} * \pi_{GAP})$$

where λ_{inf} is the sensitivity parameter that scales how strongly household consumption responds to deviations of inflation from its target.

Using this effective rate, household consumption is defined as:

$$C = S_{hh}^{eff} * H_H$$

Bank spending (H_B) is defined separately as a fixed proportion of the banks' balance sheet:

$$C_B = S_B * H_B$$

This structure captures how households adjust their consumption when inflation deviates from the target rate, while banks' spending evolves mechanically with their balance-sheet size.

After all those definitions, we need to define the logic of flows for the foreign sector. M_F flow is simply defined by the GDP times the ratio of exports to GDP (E_{rat}) thus:

$$M_F = GDP * E_{rat}$$

Similarly, we define the ratios for imports – for the households (I_{rat}^{hh}) and for the firms (I_{rat}^{f}) Thus, our flows M_{HH} and M_{Fimp} are defined:

$$M_{HH} = GDP * I_{rat}^{hh}$$

$$M_{F_{imp}} = GDP * I_{rat}^{f}$$

Finally, we define the logic of flows for paying dividends by the banks and the firms' sector. To define the level of dividends of the firms, we need to introduce an additional flow, defining profits of the firms' sector, defined as (F_p). We simply derive it as the difference between the profits and losses of the firms, thus:

$$F_p = C + G + S_B + M_F - (W + I_F + M_{Fimp})$$

Next, by introducing a ratio of dividends payment (FD_{rat}), we multiply it by F_p to get our flow D_F, thus:

$$D_F = F_p * FD_{rat}$$

Finally, we similarly define the rate of dividend payments by the banks (BD_{rat}) and a new flow representing banks' profit (B_p). Then level of profits in the banking sector is defined as:

$$B_p = I_F + I_G + LI_{hh} - S_B$$

and level of dividend payments to foreign shareholders in the banking sector is defined as:

$$D_B = B_p * BD_{rat}$$

After defining logic of all the flows, we should next define the values for ratios and initial stocks.

Building the model – defining values for ratios and stocks for the baseline scenario

We model the monetary flows for the small open economy and thus we should derive the approximate ratios and initial stock values for corresponding theoretical small open economy. Numerical data are stylized and scaled to maintain the traceability of the stock-flow consistency, while preserving internally consistent proportions between the sectors. All stock variables are assumed to be expressed in millions of Czech crowns. Flows and ratios are unitless proportions (e.g., 0.35 for τ), therefore:

1 unit = 1 million Czech crowns

Scaling is done for reducing numerical instability in the simulation environment and for providing a unified comparison basis across the sectors. The stock values are constructed as a scaled balance-sheet proxy, reflecting typical features of a small open economy, namely a sizeable banking sector, moderate public debt, positive household net financial assets, leveraged corporate sector, and an active foreign position.

Stock and ratio values for the baseline scenario are listed below (for a full set of definitions of behavioral equations see Table 2):

Table 1: Initial stock and parameter values of the model for the baseline scenario in real numbers

Symbol	Type	Value
H_H	Stock	5000
H_F	Stock	1500
H_G	Stock	300
H_B	Stock	4100
R	Stock	1000
H_{BROW}	Stock	800
FX_{CB}	Stock	3000
L_F	Stock	3500
L_{HH}	Stock	2000
B	Stock	3300
H_{ROW}	Stock	8000
L_{ROW}	Stock	3000
E_{ROW}	Stock	5000
B_F	Stock	1000
F_F	Stock	-2000
H_F	Stock	3000
G_F	Stock	-3000
BD_{rat}	Parameter	0,05
β_{hh}	Parameter	0,003
β_{max}	Parameter	0,06
β_S	Parameter	0,015
E_{rat}	Parameter	0,6
FD_{rat}	Parameter	0,6
GR_{ss}	Parameter	0,06
I^f_{rat}	Parameter	0,07
I^{hh}_{rat}	Parameter	0,05
π_{ss}	Parameter	0,004
r_{market}	Parameter	0,01
r_{cb}	Parameter	0,01
Lev_r	Parameter	8
Φ_p	Parameter	0,03
S_B	Parameter	0,005
S_G	Parameter	0,18
S_{hh}	Parameter	0,035
τ	Parameter	0,15
V_F	Parameter	0,3
W_S	Parameter	0,6
a_s	Parameter	0,03
a_y	Parameter	0,01
λ_{inf}	Parameter	0,15

Source: author's own elaboration

Now, after all values are defined, we can run a simulation for the baseline economic cycle scenario.

This model has important limitations that should be noted. First, it includes only financial assets and liabilities of the consolidated sectors. The logic for bank lending is also simplified. The model does not have mechanisms for loan defaults or for banks to change their lending based on risk - although it could be set exogenously through the ratios. Another limitation is the simplified foreign sector. Exports are mostly an external input, and the model does not have a full balance of payments. Some accounting operations are simplified as to their final balance sheet implications.

Simulation – baseline scenario

Before running the simulation, we need to define its settings. First, we define the simulation time period. As per the initial calibrated values, the one-time unit of simulation is approximately matching 1 quarter, thus:

1 time unit = 1 quarter

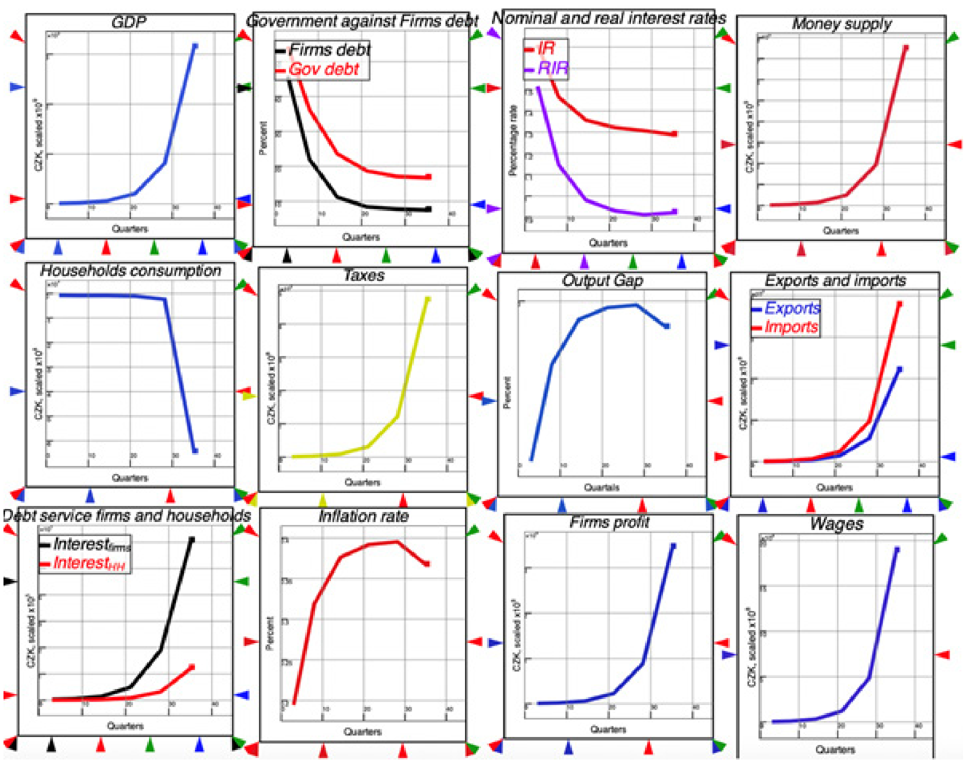
To assess the basic behavior of the model, first we run a simulation for 30 quarters. Relative error is set at 0.01 and absolute error to 0.001. Solver order is set at 4. No implicit solver is used.

The simulation results confirm strong relationship between the government and the firms' sector debts. Over 30 quarters simulation period inverse relation is observable. Increase in government debt leads to decrease in the level of firms' sector debt. Although this could be calibrated by changing the borrow offer ratios, basic observation – under simulated conditions – supports the hypothesis, that government debt as net injection of financial assets into economy means simultaneous decrease of firms' sector debt, indicating a partial substitution effect between public and private borrowing. Although 30 quarters period is not enough to fully assess the relationships between the dynamics of public debt and firms' sector profits, positive relationships could be observed there as well.

In addition to these balance-sheet effects, the baseline scenario displays a coherent set of interactions. GDP rose steadily, driven by accelerating net credit creation and strong external demand, which in turn increases exports and imports. The output gap initially widens as credit expansion outpaced its steady-state benchmark, feeding into a temporary rise in inflation. As inflation moves above the target, the real interest rate declines. Later in the simulation, as interest-rate adjustments propagate through the feedback mechanism, both nominal and real rates begin to stabilize.

The baseline scenario demonstrates well-behaved internal dynamics. Government debt expansion improves firms' profits, compresses private borrowing, and contributes to a temporary but controlled inflationary cycle driven by the widening output gap.

Figure 1: Simulated dynamics over 30 quarters. The X-axis represents quarterly time units, and the Y-axis shows values in millions of Czech crowns (scaled in the model) or in percentage points where applicable. The figure displays the trajectories of twelve key variables generated in the baseline scenario: GDP; government and firms' sector debts; nominal and real interest rates; total money supply; households' consumption; government tax revenues; the output gap; exports and imports; debt-service payments of firms and households; the inflation rate; firms' profits; and aggregate wages.

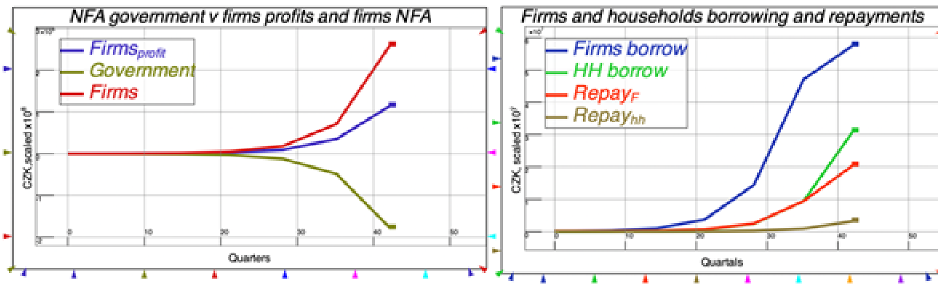


Source: Simulation in Ravel, author's own elaboration

In the baseline scenario, firms' net financial assets and profits rise strongly over the simulation horizon, while the government's net financial position declines. Firms' net financial assets grow at an accelerating pace, reaching their highest level toward the end of the period. Government net financial assets follow the opposite path, falling steadily and becoming increasingly negative.

Firms' borrowing increases rapidly throughout the simulation and becomes the dominant credit flow in the system. Household borrowing also rises but at a slower rate. Repayment flows for both sectors increase gradually, yet remain much smaller than gross borrowing, resulting in steadily growing debt levels.

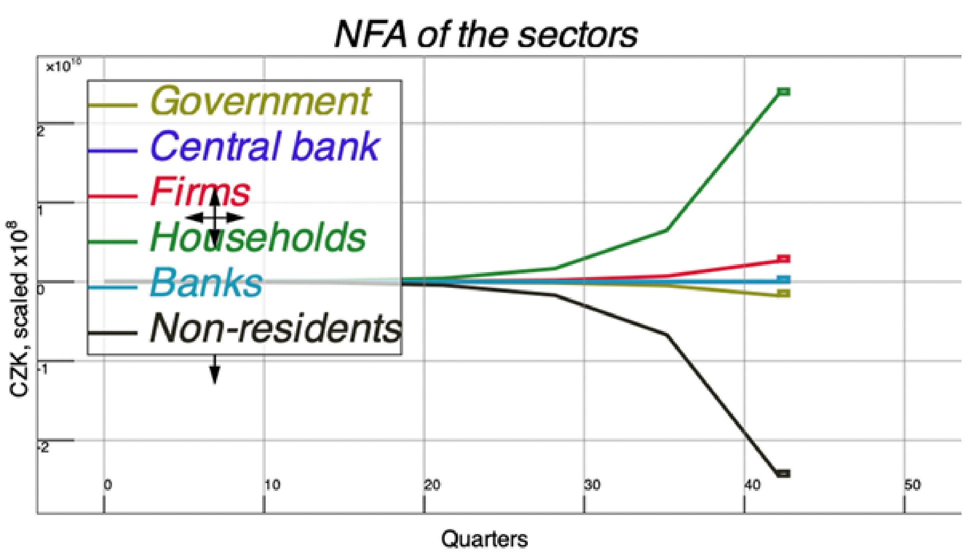
Figure 2: Simulated trajectories of sectoral financial positions and credit flows over 30 quarters. The left panel shows the evolution of firms' net financial assets, firms' profits, and the government's net financial position. The right panel displays borrowing and repayment flows of firms and households. Values are expressed in scaled CZK units.



Source: Simulation in Ravel, author's own elaboration

In the baseline scenario, sectoral net financial assets diverge significantly over the simulation horizon. Households exhibit a strong and sustained increase in their net financial position, becoming the largest surplus sector by the end of the period. Firms' net financial assets rise more moderately but remain positive. Banks and the central banks stay close to a balanced position with only minor movements. Government net financial assets gradually decline, while non-residents move into a deep negative position as the simulation progresses.

Figure 3: Net financial assets of all sectors over 30 quarters. The chart displays the simulated net financial assets trajectories of government, central bank, firms, households, banks, and non-residents. The X-axis represents quarterly time units, and the Y-axis shows values in millions of Czech crowns (scaled in the model).



Source: Simulation in Ravel, author's own elaborationY

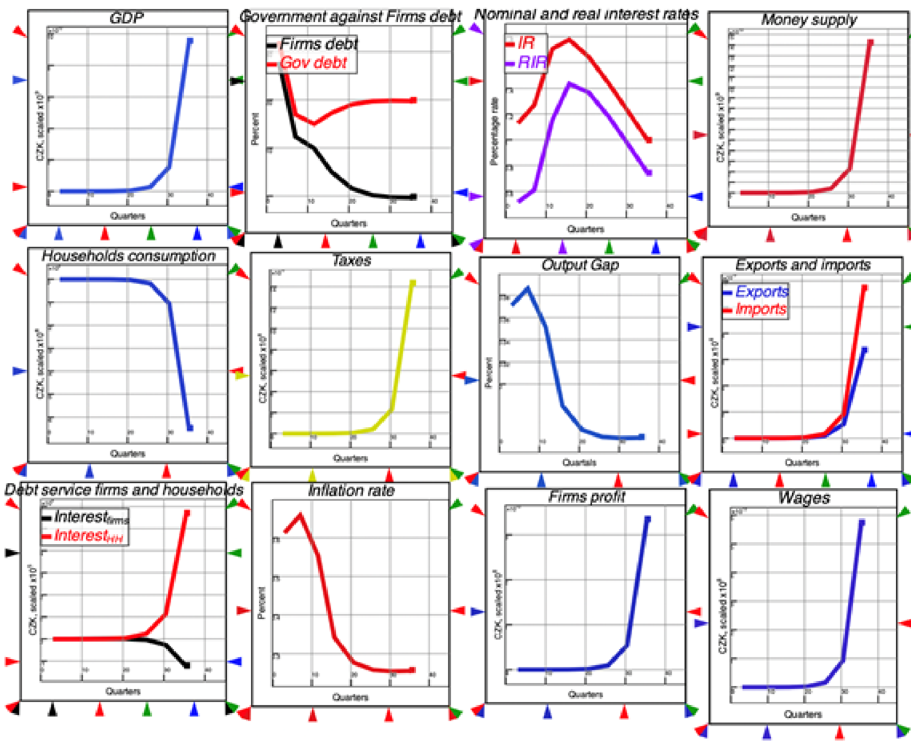
The baseline simulation confirms the standard stock-flow consistency conditions and shows that adding the foreign sector materially affects the model's dynamics. External demand supports private-sector profitability and stabilizes government net financial position, while other macro-financial variables follow a pattern consistent with a growing economic cycle.

The model also produces an inverse relationship between firms' borrowing and the interest rate, which becomes more visible when the simulation horizon is extended to 40 quarters.

Simulation – boom scenario

We introduce a coordinated boom shock by adjusting several key parameters. The export-to-GDP ratio is raised from 0.6 to 0.8, firms' borrowing capacity is increased from 0.06 to 0.14, and the repayment rate of the firms slightly is reduced, allowing stronger credit expansion. GDP, money supply, firms' profits, exports and wages accelerate sharply, reflecting the combined effect of higher external demand and easier credit conditions. Firms' borrowing rises rapidly and becomes the dominant driver of the expansion, while household borrowing increases more modestly. Taxes grow in proportion to the rising output. The output gap turns strongly positive at the beginning but gradually narrows as inflation declines toward the end of the simulation. Government debt stabilizes, while firms' debt grows, consistent with the credit-driven nature of the boom. Overall, the scenario generates a pronounced and sustained upswing in the small open economy.

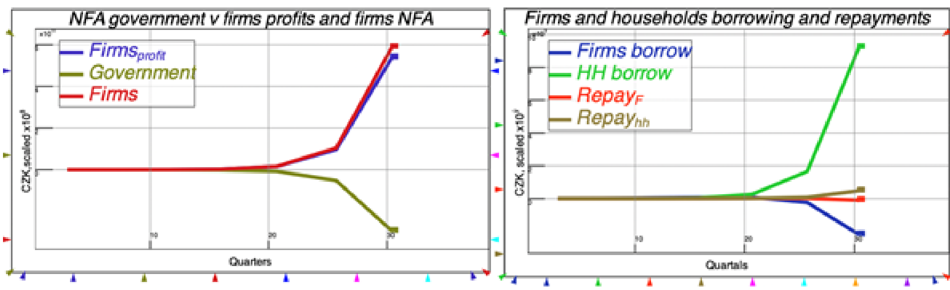
Figure 4: Simulated dynamics over 30 quarters. The X-axis represents quarterly time units, and the Y-axis shows values in millions of Czech crowns (scaled in the model) or in percentage points where applicable. The figure displays the trajectories of twelve key variables generated in the boom scenario: GDP; government and firms' sector debts; nominal and real interest rates; total money supply; households' consumption; government tax revenues; the output gap; exports and imports; debt-service payments of firms and households; the inflation rate; firms' profits; and aggregate wages.



Source: Simulation in Ravel, author's own elaboration

The boom shock leads to a pronounced increase in firms' profits and their net financial assets, while the government's net financial position declines over the simulation period. Borrowing dynamics shift markedly: firms initially expand borrowing, but the later stages of the boom are dominated by a sharp rise in household borrowing, with repayment flows remaining comparatively modest.

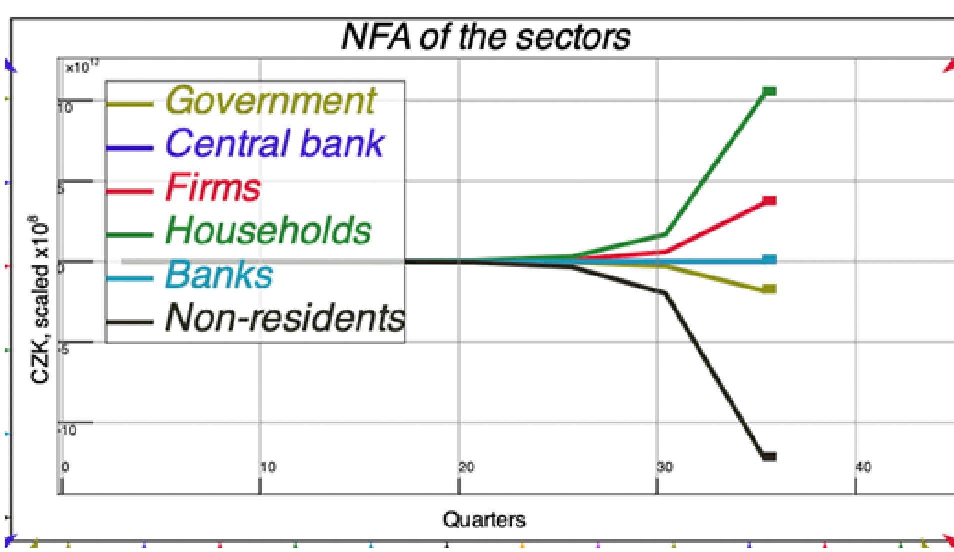
Figure 5: Simulated trajectories of sectoral financial positions and credit flows over 30 quarters. The X-axis represents quarterly time units, and the Y-axis shows values in millions of Czech crowns (scaled in the model). The left panel shows the evolution of firms' net financial assets, firms' profits, and the government's net financial position. The right panel displays borrowing and repayment flows of firms and households.



Source: Simulation in Ravel, author's own elaboration

The boom scenario generates a clear divergence in sectoral net financial positions. Households accumulate the largest surpluses, followed by firms and banks, all showing strong positive net financial assets by the end of the simulation. The government's net financial assets decline moderately, while the non-resident sector moves sharply into deficit, reflecting the stronger external imbalance associated with the expansion. The central bank remains close to a balanced position throughout.

Figure 6: Net financial assets of all sectors over 30 quarters. The X-axis represents quarterly time units, and the Y-axis shows values in millions of Czech crowns (scaled in the model). The chart displays the simulated NFA trajectories of government, central bank, firms, households, banks, and non-residents.



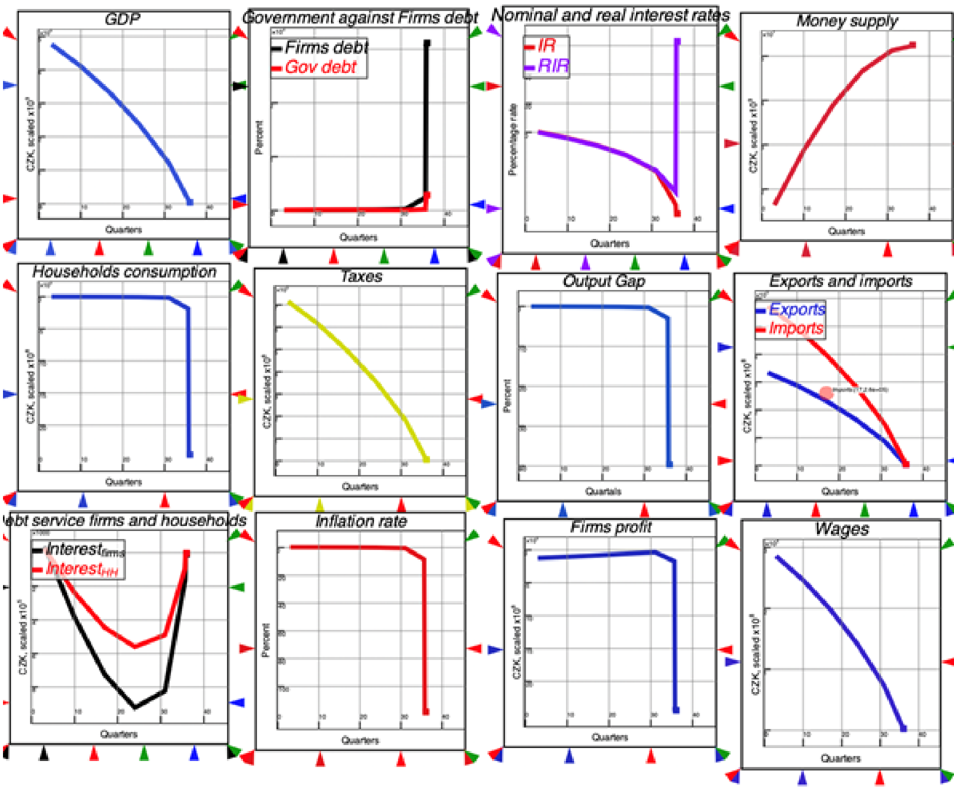
Source: Simulation in Ravel, author's own elaboration

Simulation – negative shock scenario

The negative-shock scenario is generated by tightening external and domestic demand conditions. The export ratio is reduced to 0.43, firms' turnover is cut to 0.3, while the wage share increases to 0.6. Credit conditions are tightened through a lower maximum borrowing fraction (0.08) and unchanged repayment rates, limiting firms' and households' ability to expand leverage. Government parameters remain neutral, with a tax rate of 0.21 and stable spending ratios.

The negative shock induces a contraction across majority of indicators. Output, household consumption, wages, and firms' profits decline, reflecting a broad weakening of real activity. Private borrowing collapses, while government debt rises, indicating a shift toward public-sector financing as the private sector deleverages. The export–import balance deteriorates through falling external demand, and the output gap turns markedly negative. Inflation decelerates in line with reduced demand pressures. Overall, the shock produces a consistent recessionary implication.

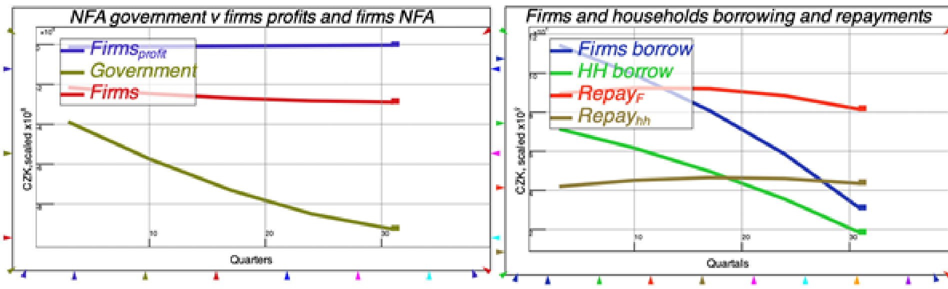
Figure 7: Simulated dynamics over 30 quarters. The X-axis represents quarterly time units, and the Y-axis shows values in millions of Czech crowns (scaled in the model) or in percentage points where applicable. The figure displays the trajectories of twelve key variables generated in the negative shock scenario: GDP; government and firms' sector debts; nominal and real interest rates; total money supply; households' consumption; government tax revenues; the output gap; exports and imports; debt-service payments of firms and households; the inflation rate; firms' profits; and aggregate wages.



Source: Simulation in Ravel, author's own elaboration

The negative shock produces a clear deleveraging pattern. Firms' and households' net financial assets improve slightly as new borrowing declines, but government net financial assets fall sharply, reflecting their role as the main absorber of the downturn. Firms' profits remain broadly stable but lower. On the borrowing side, both firms and households reduce new credit markedly, while repayment flows stay relatively rigid.

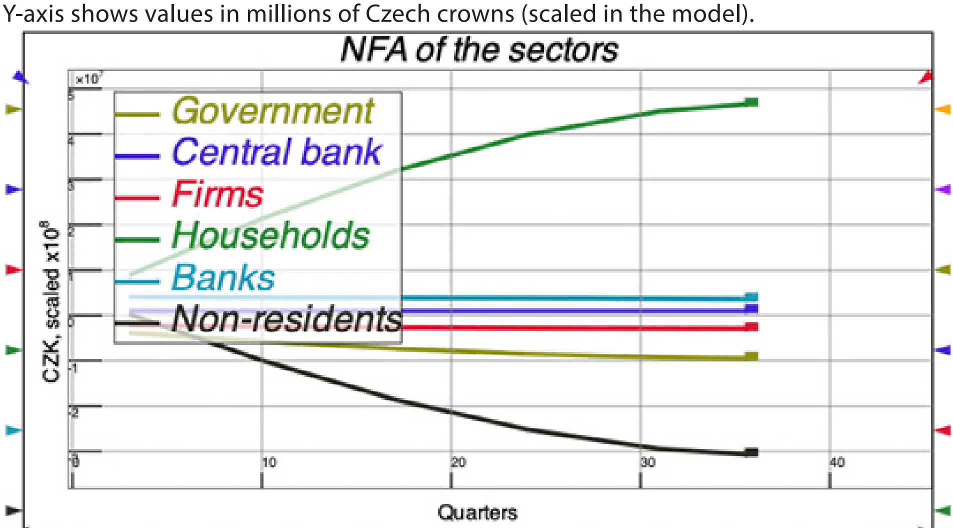
Figure 8: Simulated trajectories of sectoral financial positions and credit flows over 30 quarters in a negative shock scenario. The X-axis represents quarterly time units, and the Y-axis shows values in millions of Czech crowns (scaled in the model). The left panel shows the evolution of firms' net financial assets, firms' profits, and the government's net financial position. The right panel displays borrowing and repayment flows of firms and households.



Source: Simulation in Ravel, author's own elaboration

The negative shock generates a pronounced divergence in sectoral net financial positions. Households accumulate substantial positive net financial assets, driven by reduced borrowing and stable income flows. Firms' and banks' financial positions remain broadly flat, reflecting low credit demand and muted financial activity. In contrast, the government's net financial assets deteriorate steadily as fiscal balances absorb the downturn. Non-residents move deeper into negative net financial positions. Overall, the adjustment is characterized by rising household surpluses and a corresponding deterioration in public and external balances.

Figure 9: Net financial assets of all sectors over 30 quarters for a negative shock scenario. The chart displays the simulated NFA trajectories of government, central bank, firms, households, banks, and non-residents. The X-axis represents quarterly time units, and the Y-axis shows values in millions of Czech crowns (scaled in the model).



Source: Simulation in Ravel, author's own elaboration

Conclusions

The three simulated scenarios suggest that public debt **may positively influence** private sector financial dynamics in a small open economy. In the **baseline scenario**, increasing government debt is associated with rising firms' net financial assets and a gradual reduction in firms' borrowing, indicating a possible substitution between public and private debt. The **boom scenario** strengthens these patterns: higher external demand raises GDP, money supply, and firms' profits, while improving the net financial positions of households and firms. By contrast, the **negative shock scenario** shows that a decline in government debt and weaker external demand can negatively influence firms' net financial assets, reduce borrowing activity, and cause a broad macro-financial contraction.

These outcomes **may support** core stock-flow consistent insights - namely that government deficits can function as net financial injections and that foreign-sector flows can significantly shape domestic balance sheets. At the same time, these results underline that real-world dynamics are likely more complex, especially under adverse external conditions. Further empirical validation and more detailed modelling of foreign-sector channels would be required to support these relationships.

Table 2: Definitions of all stocks and flows of the model

Symbol	Type	Definition
H_H	Stock	$L_{hh} + W - (R_{HH} + C+T + ΦL_{HH} + M_{HH})$
H_F	Stock	$L_f + C + G + C_B + M_F - (R_F + W + F_F + D_F + M_{Fimp})$
H_G	Stock	$T + ΔB - (G + ΦB)$
R	Stock	$G + ΦB - (T + ΔB)$
H_{BROW}	Stock	$M_F - (M_F + D_F + D_B + M_{HH})$
FX_{CB}	Stock	-
L_F	Stock	$min\ (DL_F, SL_B)$
B	Stock	$(G+ΦB) - T$
H_{ROW}	Stock	$M_{Fimp} +D_F + D_B +M_{HH} - M_F$
E_{ROW}	Stock	$M_{Fimp} +D_F + D_B +M_{HH} - M_F$
B_F	Stock	$(ΦL_F + ΦL_{HH}) - (C_B + D_B)$
F_F	Stock	$C + G + C_B + M_F - (W + F_F + ΦL_F + D_F + M_{Fimp})$
HH_F	Stock	$W - (C + T + ΦL_{HH} + M_{HH})$
G_F	Stock	$T - (ΦB - G)$
G	Flow	$g_s * GDP$
T	Flow	$GDP * τ$
I_G	Flow	$LI_G * r$
W	Flow	$W_s * GDP$
C	Flow	$S_{hh}^{eff} * H_H$
M_{HH}	Flow	$GDP * I_{rat}^{hh}$
I_{HH}	Flow	$LI_{HH} * r$
$ΔL_F$	Flow	$min\ (DL_F, SL_B)$
I_F	Flow	$r * L_f$
F_P	Flow	$C + G + S_B + M_F - (W + I_F + M_{Fimp})$
Out_{GAP}	Flow	$ap * π_{GAP} + a_y * Out_{GAP}$
S_{hh}^{eff}	Flow	$S_{hh} * (1 + λ_{inf} * π_{GAP})$
r	Flow	$r^{CB} + r_{market}$
GDP	Flow	$\frac{H_F}{V_F}$
$Δr$	Flow	$\frac{(DL_F + SL_B - ΔB)\ *\ β_S}{GDP}$
DL_F	Flow	$H_F * (β^{max} - β_S * r)$
$π$	Flow	$π_{ss} + Φ_p * Out_{GAP}$
M_F	Flow	$GDP * E_{rat}$
SL_B	Flow	$B_F * Lev_r$
$π_{GAP}$	Flow	$π - π_{ss}$
M_{Fimp}	Flow	$GDP * I^f_{rat}$
M_{hh}	Flow	$GDP * I^{hh}_{rat}$
D_F	Flow	$F_p * FD_{rat}$
C_B	Flow	$S_B * H_B$
B_P	Flow	$I_F + I_G + LI_{hh} - S_B$
D_B	Flow	$B_p * BD_{rat}$
GR	Flow	$\frac{L_f + L_{hh} - R_F - R_{HH}}{H_F}$

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Disaggregated ESG Risk in European Asset Pricing Based on ESG Leaders Data

ELEONORA SALZMANN

Abstract

Background: This study investigates the conditional pricing of environmental, social, governance (ESG)-related risk exposures – specifically ESG, carbon intensity, and controversy – using portfolio-level data from firms in the Morgan Stanley Capital International Europe ESG Leaders Index (2018–2024). The sample comprises nine sector-neutral portfolios, double-sorted by ESG and Controversy scores, ensuring balanced exposure across Europe's leading ESG-rated firms.

Aim: This study evaluates how factor decomposition, macro-regime sensitivity, and time-varying risk exposure affect ESG integration in multifactor pricing models. It also assesses the effectiveness of Kalman filtering in stabilizing ESG beta estimates under data limitations.

Methodology: A two-stage Fama-MacBeth approach estimates ESG, carbon, and controversy betas using rolling regressions and Kalman filtering. These betas are then incorporated into fixed-effect panel regressions with macroeconomic volatility controls and regime interaction terms for the 2020–2021 regulatory and financial stress periods.

Results: Disaggregated E, S, and G exposures exhibit significant positive return premia, particularly under stress. Carbon and controversy factors display conditional pricing effects that intensify under transition regimes. Kalman filtering yields smoother, more interpretable beta estimates than rolling regression, enhancing model robustness.

Recommendation: ESG pricing models should incorporate factor decomposition, regime dynamics, and dynamic beta estimation, particularly Kalman filters – when working with quarterly or constrained datasets. Replicating this approach using data from multiple professional ESG providers would be valuable to assess the robustness of the pricing effects under rating divergence and disclosure heterogeneity.

Practical relevance/social implications: This study offers a replicable framework for ESG researchers and investment practitioners seeking to identify time-varying, regime-sensitive, sustainable premiums for asset pricing.

Originality/value: This study is among the first to combine ESG factor decomposition with Kalman-filtered beta estimation in a regime-augmented panel model using European portfolio data. Unlike the dominant United States-focused literature, it applies double-sorted, sector-neutral portfolios based on ESG and controversy scores. The findings demonstrate that robust ESG pricing signals can be uncovered even in small, high-quality European samples when the models are specified dynamically and contextually.

Keywords
ESG factors, Asset Pricing, European Market, ESG leaders, Carbon intensity, Controversy exposure

JEL Codes
G12, G11, Q56, C23

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Introduction

The integration of environmental, social, and governance (ESG) considerations into asset pricing models has become central to sustainable finance. Over the past two decades, scholars and practitioners have debated ESG's role in expected returns, interpreting it variously as a priced risk factor (Gregory et al., 2020; Ciciretti et al., 2023), a reflection of investor preferences (Pástor et al., 2021; Avramov et al., 2022), or a signal of firm quality and strategic advantage (Khan et al., 2016; Nagy et al., 2016). Despite the proliferation of ESG-focused models, empirical findings remain inconsistent and sensitive to methodology, factor construction, and market context (Friede et al., 2015; Blitz & Fabozzi, 2017; Berg et al., 2022).

Recent literature emphasizes that ESG factor pricing is highly conditional, often intensifying during crises or regulatory transitions (Albuquerque et al., 2020; Ramelli & Wagner, 2020). Component-level analysis may reveal more stable signals than aggregate ESG scores (Ciciretti et al., 2023; Dobrick et al., 2025). Reputational risks from ESG controversies are increasingly recognized as distinct priced exposures, particularly under heightened uncertainty (Ilhan et al., 2021; Chen et al, 2020) In parallel, carbon transition risk has emerged as a separate risk premium, driven by climate-policy developments, particularly in markets with stringent disclosure or emission-reduction mandates (Bolton & Kacperczyk, 2021; Bauer et al., 2022; Aswani et al., 2024). Therefore, this study aims to evaluate the impact of factor decomposition, macro-regime sensitivity, and time-varying risk exposure on ESG integration into multifactor pricing models.

Based on empirical design choices and findings, this study evaluates the following hypotheses:

H1 – Empirical ESG Premium Hypothesis: Exposure to disaggregated ESG components is associated with positive return premia, particularly during periods of macrofinancial stress.

H2 – Conditional Reputational Risk Hypothesis: ESG controversy exposure does not consistently predict return penalties under baseline conditions but may exhibit negative pricing effects during regulatory or market stress regimes.

H3 – Conditional Carbon Risk Hypothesis: Carbon intensity is not significantly priced in stable periods but becomes negatively associated with returns under policy transitions, suggesting the emergence of a carbon transition penalty.

This study contributes to the evolving ESG asset pricing literature by decomposing ESG-related risk exposures into three key components – ESG performance, controversial risk, and carbon intensity – and testing their pricing implications in the European equity market. A two-stage Fama-MacBeth estimation framework is applied to sector-neutral portfolios based on firms from the Morgan Stanley Capital International (MSCI) Europe ESG Leaders Index (2018–2024). Factor betas are estimated using rolling regressions and Kalman filters, with a regime interaction structure capturing the 2020–2021 period of heightened systemic stress and ESG policy acceleration.

The remainder of the paper is structured as follows. Section 1 presents the theoretical foundations of ESG pricing models, covering both conceptual frameworks and methodological challenges. Section 2 outlines the core hypotheses concerning ESG, controversies, and carbon-related return premia. Section 3 describes the data, variables, and model specifications, including regime-sensitive extensions. Section 4 presents empirical results, and Section 5 discusses their implications, focusing on the conditional nature of ESG pricing and its interpretation. Finally, Section 6 summarizes the key findings and outlines the directions for future research and model development.

1 Theoretical framework and literature

1.1 Conceptual Framework: ESG in asset pricing theory

In recent years, ESG factors have gained prominence in asset-pricing theory; however, their roles remain conceptually fragmented. ESG has been interpreted as a source of nonfinancial risk, reflection of investor preferences, signal of firm quality, and driver of strategic alpha. These interpretations reflect broader debates in financial economics regarding how intangible, often non-pecuniary, information is incorporated into asset valuation.

ESG integration in asset pricing theory has evolved across multiple frameworks. In traditional models like CAPM and Fama-French, ESG is added as a priced factor alongside size, value, and momentum (Gregory et al., 2020; Naffa & Fain, 2022) but often suffers from multicollinearity and weak significance. Arbitrage-based approaches (Pedersen et al., 2021; Pollard et al., 2017) offer greater flexibility by not assuming equilibrium, allow ESG risk exposure to vary across sectors and time. Conversely, behavioral asset-pricing frameworks emphasize investor preferences, ESG sentiment, and non-financial utility as key drivers of asset selection (Pástor et al., 2021; Avramov et al., 2022). These models suggest that ESG-related demand shifts driven by sustainability-focused investors can result in persistent price effects without traditional risk compensation. ESG preferences can be formalized through an augmented utility function that incorporates both traditional risk-return trade-offs and ESG-related preferences. These preferences can be formalized through a utility function that balances financial risk-return with ESG-related utility, as shown below:

$$U_j = E[r_p] - \frac{\lambda_j}{2} Var(r_p) + \theta_{j,t} \cdot \bar{s} - \gamma_{j,t} \cdot \overline{CONT} \quad (1.1)$$

Where U_j represents the utility of investor j; λ_j represents the investor-specific risk aversion coefficient; $\bar{s}$ represents the portfolio-level ESG score; $\overline{CONT}$ denotes the portfolio-level exposure to ESG controversies; $\theta_{j,t}$ and $\gamma_{j,t}$ are time-varying ESG preference strength and controversy aversion, respectively. This formulation shows how investors balance financial returns with ESG utility, accepting lower expected returns in exchange for sustainability or reputational quality. Future model extensions could introduce investor segmentation by varying $\theta_{j,t}$ and $\gamma_{j,t}$ across investor types, reflecting heterogeneous ESG preferences and regulatory constraints.

Similarly, intertemporal consumption models and stochastic discount factormodels incorporate ESG into marginal utility, linking it to climate risk, sustainability, and consumption smoothing (Ilhan et al., 2021; Zerbib, 2022). However, these models often rely on high-frequency data or complex parameterization, limiting their empirical use.

Others interpret ESG as a source of strategic alpha, reflecting firm-specific advantages like reputational capital, management quality, and long-term orientation – factors not fully captured by traditional models (Jensen, 1968; Khan et al., 2016; Nagy et al., 2016). ESG exposure in this view can drive persistent outperformance, especially in less-regulated or under-researched markets.

Recent empirical studies show that ESG pricing is regime-dependent, with premiums intensifying or reversing during crises or regulatory transitions (Albuquerque et al., 2020; Ramelli & Wagner, 2020). This motivates the use of regime-sensitive specifications and interaction terms, which are central to this study's design. To capture complex ESG-return relationships, recent work has introduced machine learning and nonlinear models (Feng et al., 2022; Chen et al., 2020), though these approaches trade off interpretability and transparency.

Despite growing interest, empirical evidence on ESG pricing remains mixed, often due to methodological variation, context sensitivity, and data limitations. ESG ratings diverge significantly across providers, introducing measurement noise (Berg et al., 2022), and frequently correlate with firm characteristics like size and profitability, leading to multicollinearity risks in multifactor models (Nagy et al., 2016). While meta-analyses report numerous positive findings (Friede et al., 2015), other studies highlight weak explanatory power (Blitz & Fabozzi, 2017) or note that ESG preferences may lower expected returns without improving model predictability (Pástor et al., 2022). ESG significance also tends to spike during crises and regulatory transitions (e.g., COVID-19, EU taxonomy), underscoring its regime-dependent nature. These challenges, along with ESG's dual interpretation as both a priced risk and a reflection of investor preferences, point to the need for more adaptive, context-sensitive modeling frameworks capable of isolating conditional ESG effects.

Against this background, the study adopts a simplified multifactor framework based on the Fama–MacBeth two-stage regression, treating ESG, carbon, and controversy as systematic exposures. Regime interaction terms are included to capture time-varying pricing effects, balancing empirical tractability with the need to reflect conditional ESG dynamics. The contribution lies in combining a classification framework with empirical ESG factor decomposition, integrating climate and reputational risks. While earlier models omitted heterogeneity and regime effects, the extended specification incorporates interaction terms to capture regime-dependent pricing, in line with recent studies (Albuquerque et al., 2020; Pástor et al., 2021).

1.2 Empirical literature - ESG factors in asset pricing

Integrating ESG into asset valuation presents several methodological challenges, notably in factor selection, data consistency, and market sensitivity. This study focuses on three core ESG-related factors: a decomposed ESG index, a controversy indicator, and a carbon factor – each with distinct empirical significance across markets.

Aggregated ESG scores have been widely used but show inconsistent explanatory power, especially when not disaggregated into E, S, and G components (Gregory et al., 2020; Naffa & Fain, 2022). Correlations with firm quality and profitability raise multicollinearity risks in standard multifactor models (Nagy et al., 2016; Khan et al., 2016). Moreover, ESG rating divergence across providers introduces measurement noise (Berg et al., 2022). These limitations have shifted the literature toward ESG decomposition, which improves stability and interpretability of pricing signals, especially in European and U.S. markets. Lioui & Tarelli (2022) confirm that factor construction critically affects valuation outcomes, underscoring the need for methodological precision. Theoretically, ESG can also reflect investor preferences rather than risk, aligning with Cornell's (2021) view that ESG demand is shaped by utility maximization beyond financial returns.

ESG controversy is increasingly recognized as a distinct pricing risk. Bang et al. (2023) and Chen et al. (2020) show that controversy indices capturing reputational and governance incidents significantly explain return variation in U.S. and global markets. Firms with high controversy exposure often require a risk premium due to reputational loss, especially under regulatory pressure or social tension – supporting the inclusion of controversy factors in dynamic ESG valuation models.

The carbon factor is increasingly validated as a distinct climate risk premium, particularly in European markets. Carbon-intensive firms tend to earn higher returns as compensation for transition risk (Bolton & Kacperczyk, 2021). Aswani et al. (2024) find that self-reported emissions drive pricing more strongly than third-party assessments. Carbon premia are most pronounced in jurisdictions with stringent climate policies and disclosure rules (Bauer et al., 2022). Ardia et al. (2023) further support this by showing return differentials between green and brown assets, reinforcing the case for including carbon in asset pricing models.

1.3 Overview of methodological challenges

Contemporary models of ESG integration into asset valuations demonstrate significant theoretical and empirical limitations that have remained unresolved. Despite various approaches, including ESG as an additional risk, investor preference, information signal, or strategic alpha source, most models face recurring problems that call into question the reliability and interpretability of their results.

Inconsistency of ESG ratings remains a critical issue. ESG scores vary significantly across providers (MSCI, Sustainalytics, Refinitiv, S&P), leading to low inter-provider correlation and distorted return estimates (Berg et al., 2022; Gibson Brandon et al., 2021; Tian et al., 2025). Market reactions also vary depending on the rating source (Luo et al., 2023; Serafeim, 2022). To mitigate this, the present study relies on a single provider (S&P Capital IQ), though even single-source consistency is not guaranteed.

Multicollinearity with traditional factors. ESG ratings often correlate with firm fundamentals like size, investment, and profitability (Nagy et al., 2016), causing multicollinearity, coefficient instability, and reduced statistical power. This overlap can obscure ESG's independent pricing effect.

Endogeneity of ESG measures. A further challenge arises from potential endogeneity between ESG performance and financial outcomes. Firms with strong valuations may invest more in sustainability initiatives, while improved ESG profiles can, in turn, enhance market valuation and financing conditions. This bidirectional relationship complicates causal inference and may bias estimated ESG premia if not addressed. Studies typically mitigate this through fixed effects, lagged variables, or ex-ante factor construction, although full identification remains difficult and context-dependent.

Temporary instability of ESG premiums. ESG factors often lack stable significance. Studies show that ESG premiums are weak or insignificant in normal markets but become more pronounced during crises, regulatory shifts, or periods of public pressure (Albuquerque et al., 2020; Ramelli & Wagner, 2020). This instability underscores the need for regime-sensitive modelling – an element frequently omitted in basic frameworks.

Theoretical duality of ESG interpretation. ESG is interpreted as both a risk factor and reflection of investment preferences (Pástor et al., 2021). This duality makes it difficult to specify models and complicates the interpretation of alpha. If ESG is a preference, rising prices of ESG assets may reduce expected returns, which contradicts traditional perspectives on risk premiums.

Weak identification and low reproducibility. Many models experience weak identification of ESG factors. The results often depend on the database, country, sector, or ESG score calculation method. The transferability and reproducibility of these results across samples and periods remain a serious limitation. Models often demonstrate sensitivity to the choice of specifications, which reduces confidence in the stability of their conclusions.

Institutional and political dependence. ESG premiums are shaped by local institutional factors, including regulatory frameworks, green taxonomy implementation, and political context (Pedersen et al., 2021). National climate policy has a stronger influence on carbon risk premiums than international agreements lacking domestic enforcement (Bolton & Kacperczyk, 2021). ESG disclosure quality and transparency also affect firms' access to financing (Guo et al., 2024). Notably, carbon premiums tend to be lower in countries with strong democratic institutions and rule of law (Bolton & Kacperczyk, 2021). Market responses to events like the Paris Agreement underscore that political and regulatory shifts significantly influence ESG pricing, reinforcing the need for regime-sensitive, institutionally grounded models. This regulatory dynamic culminated in the European Union's sustainable finance framework – anchored in the EU Green Deal, the Sustainable Finance Disclosure Regulation (SFDR 2019/2088), and the Corporate Sustainability Reporting Directive (CSRD 2022/2464 amending Directive 2013/34/EU) – which together institutionalized ESG disclosure and risk integration. The 2020–2021 transition period analysed in this study aligns with these legislative milestones, capturing the onset of standardized ESG reporting and supervisory expectations across the European market.

Despite theoretical progress, ESG pricing models still face key limitations – namely, rating inconsistency, multicollinearity, temporal instability, theoretical ambiguity, and low reproducibility. These issues call for hybrid, adaptive models that account for regime effects, data quality, and institutional variation. This study addresses several of these challenges by using a single data provider (S&P Capital IQ), decomposing ESG components, treating controversy and carbon as distinct priced factors, and incorporating regime interactions. This improves robustness and enhances the interpretability of ESG pricing effects.

2 Data and variable justification

2.1 Data sample based on S&P capital IQ

This study utilizes S&P Capital IQ Pro[1] as the primary data source, in line with industry practice among analysts, valuation experts, and risk managers. The platform offers high-quality, consistent ESG and financial data. A key challenge was identifying relevant firms for the European market, which lacks a predefined target universe. To resolve this, the

1 *S&P Capital IQ Pro is an analytics platform from S&P Global that provides access to a wide range of financial, market and ESG data, including MSCI ratings, asset returns, market indices, and macroeconomic variables. https://www.spglobal.com/market-intelligence/en/solutions/products/sp-capital-iq-pro*

study selects constituents of the MSCI Europe ESG Leaders Index, a transparent, sector-balanced benchmark featuring large- and mid-cap firms with strong ESG reporting and regulatory alignment. This ensures compatibility with Capital IQ's structure, minimizes data gaps, and provides historical ESG scores and carbon emissions at the firm level.[2]

The sample is not representative of the entire European market but serves as a high-quality panel for testing ESG pricing models in a controlled, observable environment. Due to limited ESG and carbon disclosure prior to 2017, the multicounty design is constrained. The final dataset comprises nine factor-mimicking portfolios from MSCI Europe ESG Leaders (Q1 2018–Q4 2024), based on firms with consistent index inclusion and complete ESG and carbon data. ESG pricing studies often rely on portfolio-level returns rather than individual firm data (Lioui & Tarelli, 2022; Gregory et al., 2020; Pástor et al., 2021; Giese et al., 2019). This approach – focused on factor portfolio construction – offers a robust and methodologically consistent framework. The use of a smaller but curated portfolio panel aligns with best practices and confirms that ESG return premia can be analysed without requiring large firm-level cross-sections.

2.2 Variables definition and data sources

This empirical model uses four key variables, each capturing an important aspect of ESG-driven asset pricing. Their selection is based on both academic literature and practical considerations of data availability and analytical relevance (Table 1).

Total return: It represents the quarterly return on an asset, including both changes in market price and dividends received. This acts as a dependent variable and reflects the total benefits received by investors. The use of total returns aligns with standard asset-pricing methodologies (Fama and French, 1992; Pástor et al., 2021; Mohanty & Ivanov 2021), enabling a direct assessment of the various risk factors' contributions in explaining returns.

Beta market (β_{Market})**:** It reflects the sensitivity of an asset's return to overall market movements and is a core variable in classical asset pricing models such as CAPM and Fama-French (Fama & French, 1992). It is consistently included in ESG-linked asset-pricing research to control for systematic risk and isolate ESG-specific effects (Mohanty & Ivanov,

2 *Attempting to build a broader dataset outside the MSCI ESG Leaders Index would not guarantee the availability of historical ESG data. Moreover, consistent reporting of carbon emissions represents additional challenge. DitchCarbon is used to source information on initially selected companies from MSCI ESG Leaders Index. Therefore, such an approach could likely increase the number of firms with incomplete reporting, particularly in the early years (2015–2016), where ESG disclosure was limited and S&P data coverage was thinner. Additionally, the costs of expanding the dataset – given the pay-per-point structure of many ESG data vendors – could introduce significant financial and practical constraints, without assurance of sector balance or methodological consistent. Therefore, selecting the MSCI Europe ESG Leaders Index is not only conceptually aligned with market standards but also a pragmatic data-driven decision that ensures long-term ESG reporting consistency and data quality, enabling the construction of a balanced panel without artificial data imputation or speculative firm selection.*

2021; Pástor et al., 2021). Gregory et al. (2020), Geczy et al. (2021), Mohanasundaram (2024), and Dobrick et al. (2025) retain market beta as a critical factor in their ESG-augmented models, confirming its continued significance and explanatory power. Across these studies, market beta remains essential for accurately capturing the portion of asset returns driven by general market risk, even when ESG factors are introduced.

Table 1: Description of variables used in the empirical model

Variable	Description	Calculation method / source
Total Return	Quarterly return on the asset, including price movements and dividends	Calculation based on market data, S&P Capital IQ Pro
Beta_ Market	Sensitivity of the asset's return to a market index	Rolling regression on yields MSCI Europe
Risk-Free Rate	Three-month EURIBOR rate reflecting risk-free yields	European Interbank Market Data, ECB Statistical Data Warehouse[3]
Beta_ESG (E/S/G)	Sensitivity to the ESG factor reflecting the sustainability of companies	Returns of portfolios sorted by ESG, S&P Capital IQ Pro
Beta Controversy	Sensitivity to negative information about ESG (scandals, violations, etc.)	Portfolio returns sorted by level of controversy; Systainalytics,[4] Corporate and Investor reporting
Beta Carbon	Sensitivity to carbon intensity (emissions-adjusted exposure)	Assigned based on reported carbon emissions (scope 1-3)[5] provided by DitchCarbon at no financial cost in support of academic research, and used as an explanatory factor in second-stage panel regressions; not used in portfolio sorting
Policy Dummy	Dummy variable for relevant regulatory or policy events impacting ESG	Author-encoded based on the timeline of major EU climate and ESG policy events[6]

3 *European Central Bank. (n.d.). ECB Statistical Data Warehouse. https://sdw.ecb.europa.eu/*

4 *Sustainalytics is a leading ESG analytics company owned by Morningstar. It provides ESG risk ratings and assessments for companies around the world, https://www.sustainalytics.com/*

5 *Due to inconsistent availability of emissions intensity data (e.g., carbon emissions per unit of revenue), the author uses absolute emission values and applies cross-sectional normalization within each year to construct a comparable carbon score ranging from 0 to 1:*

$$cs_{i,t} = Emissions_{i,t} - \min_j(Emissions_{j,t} / max(Emissions_{j,t}) - min(Emissions_{j,t}).$$

This score reflects the relative carbon footprint of firm i in year t, where higher scores indicate higher emissions relative to industry peers. For firms with missing or incomplete emissions data, a static carbon proxy (such as the DitchCarbon rating) may be used to preserve cross-sectional coverage. For firms with partial carbon reporting histories, missing intermediate years were imputed using Huber regression, which provides a robust trend estimation that is resistant to outliers while maintaining sensitivity to underlying emission trajectories. This approach ensures a continuous and comparably scaled carbon score series across the entire sample period.

6 *The policy dummy is constructed to capture the impact of key European ESG regulatory and policy milestones. Events encoded include: (1) the release of the HLEG Final Report on 31/01/2018, which laid the foun-*

Macro-financial Control Variables	Controls for market volatility, systemic stress, and energy shocks	VSTOXX (volatility), CISS (systemic stress), and Brent oil prices (energy shocks); sourced from ECB and market data

Source: Author calculations based on data from S&P Capital IQ Pro, Sustainalytics, DitchCarbon, ECB Statistical Data Warehouse, and market sources as detailed in the table.

Beta ESG factor (β_{ESG})**:** This factor measures the sensitivity of asset returns to portfolios sorted by ESG scores. It allows testing for a potential "resilience premium" and captures whether ESG acts as a priced risk or a preference channel (Pástor et al., 2021; Chen et al., 2020). Empirical applications by Gregory et al. (2020), Geczy et al. (2021), and Dobrick et al. (2025) confirm ESG betas as valid factors beyond traditional risks. Chen et al. (2020) develop sentiment-driven ESG betas, while Kumar (2023) finds alpha enhancement in regional markets, with weaker effects in global portfolios. ESG betas remain significant in regional studies, including India (Mohanasundaram, 2024). Overall, ESG betas reflect investor preferences and sustainability-driven return expectations.

Beta environmental factor (β_E)**:** It measures the sensitivity to portfolio returns sorted by environmental valuations (e.g. CO_2 emissions, energy efficiency, and waste management). Environmental risks – especially carbon exposure – drive significant pricing effects via global carbon premiums and tail risks (Bolton & Kacperczyk, 2021; Ilhan et al., 2021). A dynamic greenium emerges when climate policies are perceived as credible (Alessi et al., 2023). Geczy et al. (2021) confirm the central role of environmental factors in ESG pricing models.

Beta social factor (β_S)**:** It measures the sensitivity to social aspects (e.g. workers' rights, safety, and community participation). Evidence is mixed: Bae et al. (2021) find limited protection during COVID-19, while Mohanty & Ivanov (2021) highlight reduced idiosyncratic tail risk. Gregory et al. (2020) and Geczy et al. (2021) incorporate social factors into ESG models, typically within composite scores.

Beta Governance Factor (β_G)**:** It reflects the importance of corporate governance (e.g., board structure, shareholder rights, transparency of reporting). Governance factors significantly influence ESG return patterns and help identify firms with strong internal controls (Ciciretti et al., 2023). Geczy et al. (2021) and Pollard et al. (2017) treat governance as a core component in extended ESG pricing models.

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dation for the EU sustainable finance framework; (2) the launch of the European Green Deal on 11/12/2019, which committed the EU to climate neutrality by 2050; (3) the introduction of SFDR Phase I on 10/03/2021, requiring ESG risk disclosures from financial market participants; (4) the adoption of the EU Taxonomy Climate Delegated Act on 21/04/2021, which defined sustainable economic activities; (5) the ECB's first climate stress test on 08/07/2022; (6) the issuance of EBA ESG risk guidelines on 24/10/2022; (7) the adoption of CSRD Phase I on 05/01/2023, expanding corporate ESG reporting; and (8) the introduction of SFDR Phase II Regulatory Technical Standards on 01/07/2023, which operationalized ESG product classifications and reporting.

This decomposition clarifies which ESG component most strongly influences asset returns and avoids mispricing risks from excessive score aggregation, as warned by Berg et al. (2022) and Tian et al. (2025), who emphasize the risk of mispricing owing to ESG rating divergence. While this study's baseline model uses the composite β_ESG (as in Pástor et al., 2021; Dobrick et al., 2025), E/S/G decomposition is applied in the extended analysis to capture dimension-specific effects more accurately.

Beta Controversy ($\beta_{Controversy}$)**:** Controversies are incidents, scandals, or violations related to companies' ESG practices. This variable captures the sensitivity of returns to reputational risk factors, based on ESG risk data from sources such as Sustainalytics. Studies show that controversies often trigger return penalties – especially when unexpected or at odds with a firm's perceived ESG profile (Serafeim et al., 2022; Kölbel et al., 2020). Chen et al. (2020) link ESG news shocks to short-term return predictability. Dobrick et al. (2025) confirm controversy effects even after controlling for ESG scores. Pollard et al. (2017) treat controversy as a priced ESG premium, while Gregory et al. (2020) highlight amplified impacts in transparency-sensitive sectors. This variable complements the ESG factor by capturing short-term pricing effects not fully embedded in long-term ESG ratings.

Beta Carbon (β_{Carbon})**:** Carbon exposure is derived from firm-level emissions data (Scopes 1, 2 and 3)[7]. Unlike ESG and Controversy, it is not used for portfolio sorting but is included directly in the return regression to test for a carbon transition premium. Firms with higher emissions may earn higher expected returns as compensation for transition risk (Bolton & Kacperczyk, 2021). Ilhan et al. (2021) emphasize carbon tail risk, while Alessi et al. (2023) highlight that carbon betas shift dynamically with regulatory changes and investor sentiment. The pricing effect varies by intensity measures, construction methods, and market conditions (Bauer et al., 2022; Aswani et al., 2024). Dobrick et al. (2025) find that carbon risk remains significant after controlling for ESG and controversy factors. Pollard et al. (2017) treat carbon transition risk as a distinct, priced factor. Including a carbon-specific variable captures regulatory exposure, pricing mechanisms, and decarbonization pressures overlooked by aggregate ESG metrics.

Regime Dummy: A regime dummy identifies the 2020–2021 period of market stress and regulatory change (e.g., COVID-19 and the EU Green Deal). It interacts[8] with ESG-related betas (social, governance, carbon, controversy) to test for conditional pricing effects. This approach aligns with studies emphasizing time- and policy-sensitive ESG valuation (Albuquerque et al., 2020; Pástor et al., 2021).

7 *Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased energy), and Scope 3 (all other indirect emissions along the value chain).*

8 *A binary regime dummy variable Dt was constructed to capture the 2020–2021 period of heightened market stress and regulatory momentum. This period aligns with the onset of the COVID-19 pandemic, significant volatility in European equity markets, and the formal rollout of the EU Sustainable Finance Disclosure Regulation (SFDR) and Green Taxonomy. The dummy takes the value 1 for all observations from 2020 Q1 through 2021 Q4, and 0 otherwise. This allows the model to test for structural changes in the pricing of ESG-related risk factors during a period of systemic disruption and policy transition.*

Control Variables: To ensure the robustness of the ESG sensitivity estimates, the model includes key macroeconomic control variables, as supported by the literature. Volatility shocks are controlled for using the European market volatility index (VSTOXX index), the European equivalent of the Volatility Index (VIX) and helps isolate ESG-related effects from general market turbulence (Rouwenhorst, 1999; Pástor & Veronesi, 2013; Cederburg & O'Doherty, 2016). CISS, the Composite Indicator of Systemic Stress, measures financial instability across European markets (Hollo et al., 2021; Acharya et al., 2017).

Descriptive statistics (Table 2) indicate sufficient variation across key variables. The *Total Return* exhibits substantial variability, with an average quarterly return of 2.82% and a wide range from -62.93% to +107.61%, which is typical for equity datasets.

Table 2: Summary of descriptive statistics

Variable	N	Mean	SD	Min	Med	Max
Total Return	2744	0.0282	0.1480	-0.6293	0.0261	1.0761
ESG Score	2744	55.3706	17.3474	14.0000	54.0000	91.0000
E-Score	2744	61.4049	20.8914	2.0000	63.0000	98.0000
S-Score	2744	52.0190	18.6720	9.0000	50.0000	95.0000
G&E-Score	2744	54.1990	16.2115	13.0000	52.0000	92.0000
Carbon Score	2744	0.0441	0.1281	0.0000	0.0140	1.0000
ESG Controversy Level	2744	1.5955	0.7333	1.0000	1.0000	4.0000
VSTOXX	2744	0.0814	0.5239	-0.3600	-0.0526	2.4832
CISS	2744	0.5373	2.2926	-0.7152	-0.0323	11.5983
EURIBOR -3M	2744	-0.1345	1.0117	-5.2262	0.0009	1.0413

Source: Author calculations based on data from S&P Capital IQ Pro, Sustainalytics, DitchCarbon, ECB Statistical Data Warehouse, and market sources as detailed in the table.

The dataset covers the quarterly observations of firms using the MSCI Europe ESG Leaders Index between 2018 and 2024. The total return distribution is moderately right-skewed (0.26), with fat tails (kurtosis 5.52), indicating a high likelihood of extreme return events. ESG scores are broadly distributed, with environmental scores typically higher than social and governance scores. The carbon Score distribution is highly right-skewed (5.32) with significant kurtosis (35.99), suggesting a concentration of low-carbon firms, but with a few high-emission outliers. The ESG Controversy variable shows a similar right-skewed pattern. Macro variables such as VSTOXX and CISS exhibit significant volatility and fat tails, consistent with financial stress periods. The panel is balanced and sector-diversified but inherently reflects an ESG selection bias, which favors firms with stronger sustainability profiles and lower controversy exposure.

2.3 Conceptual challenges and insights

One key challenge regarding the integration of ESG factors into asset-pricing models is inconsistent ratings. Different methodologies among providers (MSCI, Sustainalytics, and Refinitiv) lead to varied ESG assessments for the same company, reducing ESG's reliability as a quantitative indicator. Furthermore, ESG factors' correlation with market style variables (size and value) often causes multicollinearity in models. Asset sensitivity to ESG can change owing to market conditions, political cycles, and information shocks. Additional issue is investor heterogeneity. Currently, the model assumes homogeneity, and future versions will address varying investor preferences and constraints. Notably, ESG strategies are increasingly determined by regulatory requirements (e.g., carbon footprint). These aspects will be formalized in extended versions of the model. Hence, this study uses a simplified specification to identify basic relationships. The full implementation, including dynamic coefficients, modes, and investor heterogeneity, will be developed in future work.

3 Methodology

3.1 Empirical model and its testing

This section illustrates how a basic panel regression can capture the key relationships between asset returns and ESG-related factors, even without accounting for interactions, investor segmentation, or macro-regulatory dynamics. The study aims to provide an intermediate analytical bridge between the general specifications of the model and its full implementation, as described in the following sections.

The following model (Eq. 3.1) is used as a simplified version, where $E[R_{i,t}]$ is the expected return on asset *i* at time *t*, $\beta_i^{(k)}$ represents asset i's exposure to risk factor *k*, λ_k denotes the premium associated with factor *k*, and k ∈ {Market, ESG, Carbon, Controversy}

$$E\left[R_{i,t}\right] = \lambda_0 + \sum_{k=1}^{K} \lambda_k \beta_i^{(k)} + \varepsilon_{i,t} \tag{3.1}$$

This formulation assumes that ESG-related characteristics, such as environmental performance or controversy exposure, can influence expected returns in a manner comparable to that of classical risk factors. These factors may act as price risk, quality signals, or investor preference channels. The model is extended by adding $Beta_{Carbon}$ and decomposing $Beta_{ESG}$ into its ESG components, which provides greater insight into the underlying sources of variation. However, a moderate inverse correlation exists between $Beta_{ESG}$ and $Beta_{Controversy}$ ($r = -0.53$, $p < .001$). The inclusion of both factors in the model is justified: $Beta_{Controversy}$ reflects a specific reputational dimension not captured by the aggregated ESG indicator, and it shows consistent negative significance in empirical tests. Thus, it adds explanatory power and constitutes a critical component of ESG-related risk assessments.

This base model is based on two hypotheses: (H1) a positive ESG premium and (H2) a negative reputational (controversy) premium. The simplified structure enables clear identification of these effects using fixed- and random-effects estimators. The model follows the Fama-MacBeth two-step estimation approach and assumes a linear dependence of returns on predetermined factor sensitivities. This simplified specification enables the identification of whether ESG and controversy factors are priced without imposing structural assumptions. It maintains interpretability through a linear framework and provides a benchmark for more complex models in future research. Despite its limitations, baseline regression provides a stable foundation for testing the main and secondary hypotheses. The performance and interpretability of ESG-related factors in this framework inform model refinement in the subsequent sections.

3.2 Data processing and portfolio formation

3.2.1 Data Processing, Portfolio Construction, and Factor Design

The dataset contains quarterly firm-level observations from Q1 2018 to Q4 2024 on ESG scores, carbon exposure, and ESG controversies. Only firms with complete time-series data for all three variables are included, resulting in a balanced panel. Firms with missing data are excluded rather than imputed to ensure data integrity. Data diagnostics include descriptive statistics (mean, variance, skewness, kurtosis), distribution checks (histograms, kernel density plots), and multicollinearity tests using variance inflation factors. Stationarity is assessed using panel unit root tests: Levin-Lin-Chu, Im-Pesaran–Shin, and Fisher-type ADF. Nonstationary variables are differenced as needed.

To correct for structural differences across industries, sector-neutral normalization is applied. Firms are grouped by GICS Level 2 sector, and ESG, controversy, and carbon scores are converted into percentile ranks (0–100) within each sector for each quarter. This mitigates sector bias – especially in carbon-intensive industries – and ensures comparability of scores across firms and time. The core ESG and controversy factors are constructed using a portfolio-sorting approach consistent with standard methodologies in ESG asset pricing (Lioui & Tarelli, 2022; Gregory et al., 2020; Pástor et al., 2021).

The ESG factor returns are calculated as follows in Eq. 3.2. The controversy factor return is calculated as in Eq. 3.3.

$$R_{ESG,t} = \frac{1}{N_{high}} \sum_{i \in Top} R_{it} - \frac{1}{N_{low}} \sum_{i \in Bottom} R_{it} \tag{3.1}$$

$$R_{CONT,t} = \frac{1}{N_{low}} \sum_{i \in Low} R_{it} - \frac{1}{N_{high}} \sum_{i \in High} R_{it} \tag{3.2}$$

$$CS_{it} = \frac{Emission_{it} - \min(Emission_t)}{\max(Emission_t) - \min(Emission_t)} \tag{3.3}$$

Carbon exposure is calculated at the firm level (see 3.3) and used as an independent variable in return regressions, not for portfolio sorting. This normalization makes carbon exposure comparable across firms and periods, enabling its direct use in second-stage regressions without portfolio sorting. These factors are used to estimate portfolio betas in the subsequent time-series regressions. Then, the firms are sorted each quarter into nine portfolios using a double-sorting approach: first by ESG scores and then by controversy levels, each divided into terciles (low, medium, high). This structure isolates the joint effects of ESG performance and controversy exposure on returns and tests whether high ESG scores offset reputational risks. Portfolios are rebalanced quarterly to reflect updated ESG and carbon data. Outliers in the top and bottom 1% of carbon and controversy scores are reviewed but not winsorized, as sensitivity checks show minimal impact on results. Portfolio returns are value-weighted by market capitalization to reflect realistic investment practices and reduce small-cap bias.

Returns are calculated as in formula 3.4, where $R_{p,t}$ represents the return on portfolio pat time; $w_{i,t}$ denotes the market capitalization of firm i at time t; $R_{i,t}$ denotes the total return of firm i at time t; and $i \in p$ denotes all firms in portfolio p.

$$R_{p,t} = \frac{\sum_{i \in p} w_{i,t} \cdot R_{i,t}}{\sum_{i \in p} w_{i,t}} \tag{3.4}$$

The study design reflects a practical balance between cross-sectional diversity and statistical robustness. This aligns with methodologies in recent ESG asset pricing studies, such as Lioui & Tarelli (2022), Gregory et al. (2020), and Pástor et al. (2020/2022), which implement ESG factor portfolios using limited sets of quantile- or factor-based portfolios rather than large firm-level regressions.

3.2.2 Beta Estimation and Second-Stage Modeling

Betas are estimated using two complementary methods to ensure robust results under the constraint of limited quarterly data frequency:

1. Fama-MacBeth Two-Stage Procedure (Rolling Betas): A two-stage Fama-MacBeth procedure is used to estimate portfolio-level betas via rolling eight-quarter regressions, following Ilhan et al. (2021) and Ciciretti et al. (2023). While traditional asset pricing studies use longer rolling windows (30–60 observations) made possible by high-frequency data, ESG research typically relies on quarterly or annual updates. This lower frequency limits the available time series length. Accordingly, the literature accepts shorter rolling windows – commonly 8–12 quarters – to accommodate the slower update cycles of ESG and carbon data.[9]

Step 1.a $$R_{i,t} = \alpha_t + \beta_i^{mkt} F_t^{mkt} + \beta_i^{ESG} F_t^{ESG} + \beta_i^{CONT} F_t^{CONT} + \ldots + \varepsilon_{i,t} \quad (3.5)$$

Here, $R_{i,t}$ is the return on asset *i* at time *t*, and F_t represents factor realizations. The estimated betas reflect each portfolio's sensitivity to market, ESG, controversy, and, later, carbon.

2. Kalman Filter (Time-Varying Betas): Alessi et al. (2023) use a Kalman filter to estimate time-varying betas. Unlike rolling windows, it updates estimates as new data arrive by combining prior information with current returns in a Bayesian state-space framework, typically expressed in Eq. 3.6:

Step 1.b $$\begin{cases} R_{i,t} = \alpha_t + F_t' \beta_{i,t} + \varepsilon_{i,t} & \text{Measurement Equation} \\ \beta_{i,t} = \beta_{i,t-1} + \nu_{i,t} & \text{Transition Equation (3.6)} \end{cases}$$

Where $R_{i,t}$ represents portfolio return at time *t*, α_t represents an intercept (can be time-varying or fixed), F_t' defines vector of observed factor realizations (e.g., market, ESG, controversy) and $\beta_{i,t}$ represents a vector of time-varying betas. Normally distributed measurement noise and process noise are denoted $\varepsilon_{i,t}$ and $\nu_{i,t}$, respectively. The Kalman filter is well-suited for lower-frequency data, such as quarterly ESG scores, as it avoids fixed window selection and yields smoother, more stable beta estimates. However, its application requires more complex modeling and stronger assumptions, which may limit its practical applicability. To enhance robustness, this study applies both the Fama-MacBeth and Kalman filter methods in parallel, reducing reliance on a single technique. Combined with sector-neutral adjustments, this dual-beta approach supports meaningful cross-sectional variation and aligns with best practices in ESG asset pricing literature.

In the second step, these estimated betas are used in panel regressions to test pricing effects (Eq. 3.7 below). The coefficients λ reflect the extent to which exposure to each factor is compensated for or penalized in expected returns.

Step 2 $$R_{i,t} = \lambda_0 + \lambda_1 \widehat{\beta_{i,t}^{mkt}} + \lambda_2 \widehat{\beta_{i,t}^{ESG}} + \lambda_3 \widehat{\beta_{i,t}^{CONT}} + \ldots + u_{i,t} \quad (3.7)$$

3.2.3 Model extensions: Regime sensitivity and macro controls

This study extends the model by interacting ESG-related betas with a regime dummy[10] for the 2020–2021 stress period to capture conditional pricing effects. This approach identifies ESG-related risk premia without assuming specific investor preferences or market equilibrium. To account for broader conditions, the model includes macro-

9 *The initial dataset spanned from 2015 to 2024. However, 2015 to 2017 is excluded owing to incomplete or inconsistent availability of ESG subcomponent scores and carbon emission data across firms. Beginning in 2018 ensures full coverage and comparability across all explanatory variables.*

10 *A regime dummy variable is defined to identify the 2020–2021 period, representing heightened market stress and regulatory momentum (COVID-19, EU Green Deal rollout). This dummy is interacted with each ESG-related beta to capture regime-dependent return sensitivities.*

financial controls: VSTOXX (volatility), CISS (systemic financial risk), and Brent oil prices (energy shocks relevant to carbon-intensive firms). These controls help isolate ESG effects from macroeconomic noise.

$$E[R_{i,t}] = \alpha_i + \gamma_t + \beta' X_{it} + \delta' (X_{it} \times D_t) + \Phi' Z_t + \varepsilon_{it} \tag{3.8}$$

The resulting specification is a regime-sensitive, macro-adjusted panel model expressed as in Eq. 3.8., where: X_{it} represents a vector of ESG-related factor exposures; β represent the unconditional (baseline) factor loadings. D_t represents the regime dummy (1 if 2020–2021, 0 otherwise). δ' represents the incremental factor loadings during the regime. $X_{it} \times D_t$ represents elementwise interaction of each ESG beta with the regime indicator. $\Phi' Z_t$ represents the vector of macro-financial control variables (VSTOXX, CISS, Brent oil prices) and their associated loadings, capturing the impact of market volatility, systemic financial stress, and energy price fluctuations on asset returns. α_i captures firm-specific effects (fixed effects) and γ_t denotes optional time effects.

The suggested model enables consistent comparisons across models with different sets of risk factors, including ESG decomposition and carbon exposure, while accounting for key external shocks. It tests whether ESG and related exposures are priced systematically, and whether these effects amplify, diminish, or reverse under macrofinancial stress or regulatory transitions. This model serves as a testing ground for different beta combinations and estimator types before introducing more dynamic specifications in future work.

While the fixed-effects estimator and macro-financial controls reduce omitted-variable bias, potential endogeneity between ESG performance and asset returns cannot be entirely ruled out. Reverse causality may arise if firms with strong market performance subsequently improve their ESG standing or disclosure. To mitigate this, the study constructs ex-ante factor portfolios and employs lagged beta estimation, which limit simultaneity effects. Nevertheless, future research could extend the model using instrumental variables or dynamic panel techniques to test the causal direction of ESG premia more formally.

4 Results

4.1 Preliminary data analysis

Table 2 presents descriptive statistics for the raw variables prior to factor construction, including skewness and kurtosis to assess distributional properties. The ESG Leaders sample inherently favors firms with higher ESG scores, lower carbon intensity, and fewer controversies, limiting generalizability to the broader European market. Carbon scores and controversy variables exhibit extreme right-skewness, indicating potential outlier influence on factor estimates. To address this, subsample robustness checks are conducted for high-carbon and high-controversy firms. The index-based structure and sector portfolios raise the risk of cross-sectional dependence due to shared exposure to macro shocks and policy changes. To address this, fixed effects estimators with clustered standard errors are applied. Fat tails, common shocks, and sample selection bias warrant caution in interpreting the magnitude and stability of ESG and carbon premiums.

4.2 Portfolio formation and factor construction

Table 3 presents summary statistics for factor returns across the nine ESG–controversy portfolios. Mean returns are positive, with the highest in Q2_C3 (4.30%) and the lowest in Q3_C2 (–0.44%), suggesting overall value added by ESG and controversy factors. Volatility, as measured by the standard deviation, ranges from 9.5% (Q3_C2) to 21.4% (Q1_C3), indicating varying levels of return dispersion and risk. Both low-risk (e.g., Q3_C1) and high-risk portfolios (e.g., Q1_C3) reflect different sensitivities to ESG and controversy exposure. Although detailed skewness and kurtosis are not reported, prior analysis indicates non-normal return distributions in several portfolios, with some exhibiting fat tails and downside risk asymmetries. These characteristics highlight the heterogeneous risk-return profiles driven by ESG and controversy sorting.

Table 3: Summary of descriptive statistics

Portfolio	Mean Return	Std. Dev.	Minimum	Maximum	N
Q1C1	0.02496	0.12256	–0.25182	0.35370	44
Q1C2	0.03852	0.10954	–0.20043	0.23909	48
Q1C3	0.02647	0.21399	–0.24521	1.07607	48
Q2C1	0.03578	0.13257	–0.40932	0.40815	52
Q2C2	0.02563	0.10151	–0.27231	0.23269	44
Q2C3	0.04299	0.16066	–0.40187	0.48146	36
Q3C1	0.02631	0.10153	–0.12130	0.29472	44
Q3C2	–0.00440	0.09534	–0.17294	0.23916	48
Q3C3	0.03230	0.12252	–0.24505	0.22006	44
Total	0.02726	0.13291	–0.40932	1.07607	408

Source: Author calculations based on portfolio-level returns constructed from ESG and controversy score-sorted portfolios using S&P Capital IQ Pro data and Sustainalytics ESG controversy metrics.

Before estimating rolling betas and applying the Kalman filter, the factor return series is winsorized to improve robustness. Unlike trimming, winsorization caps extreme values (e.g., at the 2.5th and 97.5th percentiles), preserving sample size while reducing outlier influence. This step is essential, as both methods are sensitive to extreme values that can distort time-varying estimates, especially under rare ESG shocks or market anomalies.

4.3 Beta estimation: Rolling vs. Kalman comparison

To capture the dynamic nature of factor exposure, the study applies both rolling window regressions and Kalman filtering. This dual approach balances responsiveness with stability in capturing portfolio sensitivities to ESG and market risks. Table 4 compares the two methods across key factors: market, ESG, carbon, control variables, and macro-volatility proxies (CISS and VSTOXX).

Table 4: Summary statistics – Kalman vs. Rolling betas

Factor	Kalman Mean	Rolling Mean	Kalman Std Dev	Rolling betas	Interpretation
Market	0.0532	0.8931	0.0407	2.2411	Rolling betas are much more reactive to short-term market shocks
ESG Factor	-0.0193	0.0650	0.0341	1.7615	Rolling shows short-term ESG tilt; Kalman sees slightly negative trend
Controversy Factor	0.0107	-0.0388	0.0297	2.0781	Kalman sees small positive loadings; Rolling fluctuates negatively.
Carbon Score	-0.0531	-135.1113	0.0471	4,616.3210	Rolling is still unstable even after z-scoring – Kalman is reliable
CISS	0.0023	0.0188	0.0171	0.2643	Systemic stress factor is more sensitive in rolling windows
VSTOXX	-0.0821	-0.0461	0.0433	0.9412	Both negative – Kalman stronger on volatility aversion.

Source: Author's estimates using Kalman filter and rolling window regression applied to MSCI ESG Leaders Index data, with macro variables from ECB and market sources.

The comparison indicates that Kalman filtering generates smoother and more stable beta trajectories, characterized by lower standard deviations across all factors. By contrast, rolling window estimates exhibit elevated short-term sensitivity to volatility and noise – particularly for carbon and controversy betas – even after normalization. Kalman filtering is more effective at capturing structural trends, such as persistent negative loadings on carbon and a weak ESG tilt, whereas rolling regressions may distort underlying exposures due to lag structures and heightened sensitivity to outliers. This analysis shows that Kalman filtering offers a favorable balance between stability and adaptability, making it particularly well-suited for estimating time-varying exposures to ESG and macroeconomic factors. Its effectiveness, however, depends on appropriate model specification and filtering assumptions. In contrast, rolling regressions – while non-parametric and conceptually straightforward – are more sensitive to outliers and regime shifts. This comparison, especially with ESG, carbon, and controversy exposures, builds on prior work (e.g., Feng, 2022) by illustrating how estimation technique affects beta stability and interpretability. The study addresses a key gap by demonstrating that in noisy, low-frequency ESG datasets, Kalman filtering improves robustness and signal clarity. These improvements are critical for capturing evolving investor preferences and for informing second-stage panel regressions that assess pricing dynamics across regimes and investor types.[11]

4.4 Panel regression results (Core model selection)

The regression results (Table 5) reveal a clear progression in explanatory power and model quality as the factor structure becomes more refined across Models 1 to 5. Model 5, which includes disaggregated ESG betas alongside carbon and macroeconomic variables, significantly outperforms earlier models. It achieves an R^2 value of 0.4917, indicating that half of the variation in portfolio returns can be explained by the model. By contrast, Models 1–4 yield lower R^2 values (below 0.1), highlighting that simple or aggregated ESG specifications fail to effectively capture the drivers of return variation.

11 *The study's findings are robust to alternative beta estimation methods and model diagnostics. The comparison between rolling and Kalman-filtered betas provides internal validation of factor stability, while the exclusion of weakly cointegrated variables (such as VSTOXX) improves statistical consistency. Nevertheless, the relatively small and high-quality ESG Leaders sample limits generalizability. Future replications using broader firm universes or multiple ESG data providers would further test the stability and external validity of these results.*

Table 5: Model specification selection

Metric / Test	Model 1	Model 2	Model 3	Model 4	Model 5
R^2 within	0.0079	0.0421	0.0079	0.0823	0.4917
AIC	–252.565	–259.413	–250.575	–264.202	–413.114
BIC	–241.977	–245.296	–236.457	–239.496	–388.408
Hausman χ^2 (FE vs RE)	$\chi^2 = 2.23$, $p = 0.526$	$\chi^2 = 6.39$, $p = 0.172$	$\chi^2 = 2.25$, $p = 0.691$	$\chi^2 = 11.44$, $p = 0.120$	$\chi^2 = 27.61$, $p < 0.001$
LM test (RE vs OLS)	$\chi^2 = 0.00$, $p > .99$	$\chi^2 = 0.00$, $p > .99$	$\chi^2 = 0.00$, $p > .99$	$\chi^2 = 0.00$, $p > .99$	$\chi^2 = 0.00$, $p > .99$
FE Preferred?	Yes*	Yes*	Yes*	Yes*	Yes
Beta_ESG	9.92 (0.228)	—	9.93 (0.229)	—	—
Beta_E	—	—	—	—	24.27 (0.013)
Beta_S	—	3.17 (0.026)	—	4.76 (0.002)	21.64 (0.001)
Beta_G	—	3.79 (0.022)	—	3.92 (0.082)	26.72 (0.007)
Beta_ Controversy	–3.43 (0.531)	2.96 (0.167)	–3.41 (0.531)	3.90 (0.200)	–0.96 (0.887)
Beta_ Carbon	—	—	–0.55 (0.895)	0.50 (0.946)	–0.96 (0.887)
Beta_CISS	—	—	—	–3.97 (0.103)	–0.12 (0.959)
Beta_ VSTOXX	—	—	—	–0.33 (0.965)	–4.05 (0.088)

** FE retained based on theoretical considerations (potential correlation between unobserved effects and regressors, small N large T structure, and preference for robust clustered inference), despite the Hausman test not rejecting RE.*

Source: Author estimates from panel regression models using fixed effects (FE) and random effects (RE) specifications. Data based on ESG factor exposures and macro-financial variables sourced from S&P Capital IQ Pro, Sustainalytics, DitchCarbon, and ECB Statistical Data Warehouse.

This pattern is further corroborated by the model selection criteria. Model 5 exhibits the lowest AIC (–413.11) and BIC (–388.41) among all specifications, demonstrating a superior fit despite its increased complexity. The steady improvement in both the AIC and BIC from Models 1 to 5 supports the value of including granular ESG components and macrofinancial controls in asset pricing. Statistical tests for the model choice reinforce these findings. Although the LM test fails to reject the null hypothesis in all models – suggesting no strong preference for random effects over pooled OLS – the Hausman test favors the fixed effects specification in Model 5 ($\chi^2 = 27.61$, $p < .001$). This indicates that unobserved heterogeneity correlates with the regressors and that the FE estimation is appropriate. Regarding factor-specific results, the aggregate ESG betas in Models 1 and 3 are statistically insignificant ($p > .2$), highlighting the limitations of composite ESG scores. This aligns with the growing academic consensus that aggregation may mask heterogeneity across the E, S, and G pillars. When disaggregated in Model 5, all three ESG components exhibit strong and statistically significant loadings: the environmental beta is 24.27 ($p = .013$), the social beta is 21.64 ($p = .001$), and the governance beta is 26.72 ($p = .007$). These findings demonstrate that separating the ESG dimensions provides more accurate estimates and deeper insights into how each factor contributes to returns. By contrast, the controversy and carbon betas remain statistically insignificant across all specifications, suggesting their influence may be nonlinear or conditional – only emerging under specific market regimes. The inclusion of macroeconomic factors such as the systemic stress index (CISS) and market volatility (VSTOXX) enhances the model. VSTOXX exhibits marginal significance in Model 5 ($\beta = -4.05$, $p = .088$), suggesting a potential pricing of volatility aversion in ESG-aligned portfolios. Taken together, these results support the conclusion that a disaggregated ESG model, supplemented by macro and volatility risk controls, yields more meaningful insights. Model 5 captures greater return variation and reveals statistically significant ESG channels that remain hidden in simpler models. This approach strengthens disaggregated and dynamic ESG factor modelling, advances prior literature, and offers a more robust framework for future empirical applications.

Although the initial specifications of Model 5 included both macro risk factors (CISS and VSTOXX), the final version of the regime-augmented model excludes VSTOXX. This decision is based on two diagnostic tests. First, Pesaran's (2004) test for cross-sectional dependence confirms the presence of significant interdependence across portfolio returns (CD statistic = 8.643, $p < .001$), suggesting that global and macro shocks affect all portfolios simultaneously. Second, Westerlund's (2007) ECM panel cointegration test[12] is used to determine whether the specified covariates form a long-run equilibrium relationship with returns. The model that includes CISS but excludes VSTOXX yields mixed cointegration evidence: the Pt statistic is –11.090 ($p = .013$), indicating rejection of the null

12 *The Westerlund test includes four statistics, among which the Pt statistic is often considered the most powerful in small samples and is particularly sensitive to panel-wide cointegration. In the results, Pt = –11.090 (p = .013) when CISS is included, supporting long-run equilibrium. Conversely, inclusion of VSTOXX yields Pt = –9.676 (p = .206), indicating failure to reject the null of no cointegration.*

hypothesis of no cointegration, whereas other statistics (e.g., Ga and Pa) are insignificant. By contrast, when VSTOXX is included, all four statistics fail to reject the null hypothesis ($Pt = -9.676$, $p = .206$), weakening the evidence for a stable long-run relationship. Based on this, only CISS is retained as a macro control in the final specification, prioritizing statistical consistency and interpretability over the inclusion of weakly cointegrated variables.

4.5 Policy regime interaction

To examine whether ESG-related risk exposure varies across market conditions, Model 5 is extended by integrating a policy regime dummy variable that captures the stress/transition period from 2020Q1 to 2021Q4, which coincides with the COVID-19 pandemic and heightened ESG-related policy intervention in Europe. This binary variable interacts with the environmental (Beta_E), social (Beta_S), governance (Beta_G), and carbon (Beta_Carbon) factor loadings to assess whether pricing effects are amplified or diminished under policy stress. By embedding these interaction terms directly into the regression framework, the model allows for conditional factor premiums, distinguishing baseline return sensitivities from those observed during systemic transitions. This augmentation of Model 5 enables the testing of time-varying ESG pricing and provides insight into whether investor preferences or market valuations of ESG dimensions change in response to macroeconomic shocks.

Table 6: Policy regime interaction model

Factor	Base Period	Stress Int. Coeff.	Net Effect (Stress Period)	p-value (Net)
Beta_E	17.18 (0.000)	19.08 (0.018)	36.26	< .001
Beta_S	17.04 (0.000)	13.91 (0.047)	30.95	< .001
Beta_G	19.62 (0.000)	12.89 (0.069)	32.50	< .001
Beta_Carbon	–0.06 (0.992)	–12.02 (0.252)	–12.08	.095
Beta_Market	–1.43 (0.376)	—	—	—
Beta_CISS	–1.11 (0.046)	—	—	—

Source: Author's estimates using interaction panel regressions between ESG betas and a stress-period policy dummy. Data sourced from S&P Capital IQ Pro, Sustainalytics, DitchCarbon, and ECB/market databases.

Under normal market conditions, the coefficients on Beta_E, Beta_S, and Beta_G are positive and statistically significant at the 1% level. This finding suggests that a higher exposure to ESG factors is associated with superior portfolio performance during stable periods. By contrast, the coefficient of the carbon score (Beta_Carbon) is not statistically significant, implying that carbon intensity does not appear to be priced under normal conditions. The systemic risk proxy (CISS) has a negative and statistically significant coefficient ($p = .046$), indicating that portfolios more exposed to macro-stress tend to underperform, even outside the stress regime.

The interaction terms between the ESG factors and the stress regime dummies, Beta_E_reg, Beta_S_reg, and Beta_S_reg, are also positive, with p-values of .018, .047, and .069, respectively. These results indicate that during the stress period, the positive return premium associated with ESG exposure became even stronger. This could reflect a shift in investor preferences toward sustainable assets, driven by both heightened uncertainty and expanding policy support for ESG-aligned investments. Although the interaction term for carbon (Beta_Carbon) is not statistically significant ($p = .252$), it is negative, and the combined net carbon effect during the stress period is marginally significant at the 10% level (–12.08, $p = .095$). This finding provides partial evidence of an emerging carbon penalty under stressed or transition-oriented market regimes. The combined effects estimated using lincom[13] further clarify this pattern. During the stress period, the environmental, social, and governance betas increased to 36.26, 30.95, and 32.50, respectively, all statistically significant at $p < .001$. These amplified betas highlight the growing return premia associated with ESG characteristics during crises. Simultaneously, carbon becomes more negatively associated with returns, reinforcing the hypothesis that investors penalize high-carbon portfolios as climate transition risks become more salient.

Overall, these findings support the hypothesis that crisis periods catalyze ESG repricing through behavioral channels (e.g. investor preference shifts), structural realignment (e.g. capital reallocation), and policy mechanisms (e.g. green recovery packages and regulatory signals). By integrating regime-sensitive effects into the beta structure, the model demonstrates that ESG risk pricing is dynamic and varies significantly across market conditions.

5 Discussion

The empirical patterns observed here are consistent with theoretical frameworks that interpret ESG premia as emerging from both risk-based and preference-driven mechanisms. Within equilibrium models such as Pástor et al. (2021), ESG demand by sustainability-oriented investors shifts relative prices and expected returns even without new risk exposure, while in heterogeneous-belief settings like Avramov et al. (2022), investors' subjective ESG valuations generate cross-sectional return differentials. The amplification of ESG premia during stress regimes in this study thus reflects both enhanced risk compensation for sustainable assets and stronger investor-preference effects under uncertainty.

13 *The lincom command in STATA is short for "linear combinations of estimators." It is used to compute and test the combined effect of multiple regression coefficients, often involving interaction terms.*

This study confirms that ESG-related factors are priced in European equity markets; however, their effects differ in magnitude, direction, and stability across components and regimes. Disaggregated ESG betas exhibit strong and statistically significant return premia under both baseline and stress regimes, with coefficients nearly doubling during the 2020–2021 transition period. Conversely, reputational risk (measured via the ESG Controversy factor) is negatively priced but lacks robustness in baseline models, gaining partial significance only under stress. Carbon exposure, although insignificant in the unconditional models, becomes negatively priced under the policy stress regime, suggesting the emergence of a transition risk penalty. These findings support the hypothesis that ESG pricing is component-specific, regime-dependent, and influenced by both market conditions and investor perception shifts. This study also demonstrates that the ESG premium estimation is highly sensitive to model specifications, particularly the decomposition of ESG factors and the inclusion of regime interaction terms.

The positive return premia with disaggregated E, S, and G betas are consistent with the findings of Ciciretti et al. (2023) and Geczy et al. (2021), who demonstrate that ESG subcomponents are more stable and interpretable when modelled separately. The coefficients – specifically governance ($\beta \approx 26.7$, $p < .01$) and social ($\beta \approx 21.6$, $p < .01$) – exceed those in Gregory et al. (2020) and Dobrick et al. (2025), suggesting that a sector-neutral, portfolio-based approach may enhance signal strength, particularly under stress.

Unlike Friede et al. (2015) and Nagy et al. (2016), who report weak and unstable ESG premiums using aggregate scores, this study finds that decomposition significantly increases explanatory power (with R^2 increasing from 0.08 to 0.49). This validates the findings of Lioui & Tarelli (2022), who emphasizes that factor construction critically affects both the magnitude and significance of ESG pricing.

Factor stability is a key issue in literature. Avramov et al. (2022) and Pástor et al. (2022) highlight that ESG-related coefficients tend to be weak or unstable unless regime interactions, investor heterogeneity, or time-varying betas are included. Our regime-augmented model confirms this: the environmental beta doubles during stress (from $\beta = 17.2$ to $\beta = 36.3$, $p < .001$), and the social and governance effects also intensify significantly. These dynamics are consistent with the findings of Albuquerque et al. (2020) and Ramelli & Wagner (2020), who argue that ESG resilience becomes particularly valuable in crisis conditions.

Conversely, carbon exposure shows non-significance in unconditional regressions – mirroring mixed evidence reported in Aswani et al. (2024) and Bauer et al. (2022) – but becomes negative and marginally significant under stress ($\beta \approx -12.08$, $p = .095$), supporting the transition risk channel outlined in Bolton and Kacperczyk (2021). This divergence suggests that carbon premia are non-linear but contingent on a political-regulatory context, consistent with the findings of Pedersen et al. (2021) and Guo et al. (2024).

This study constructs ESG beta using rolling and Kalman-filtered estimates of portfolio-sorted returns, rather than static factor loadings or ESG ratings directly, to capture time-varying ESG sensitivity. This method follows Ilhan et al. (2021) and Alessi et al. (2023)

and addresses the stability problems raised by Feng et al. (2022) and Pollard et al. (2017) by mitigating noise from raw ESG scores and rating divergence (cf. Berg et al., 2022). Compared with studies using firm-level regressions (e.g., Naffa & Fain, 2022), this approach avoids multicollinearity with size and profitability and provides cleaner estimates of ESG factor effects.

Concerning reputational risk, the findings partially support those of prior studies. While Ilhan et al. (2021) and Kölbel et al. (2020) find significant and persistent negative return effects from controversies, the baseline model is insignificant, with stronger signals emerging only under stress regimes. This divergence may reflect differences in data sources (using Sustainalytics-based tercile portfolios) and market contexts (a European, sector-neutral, and ESG-screened sample). Nonetheless, the direction of the effect remains consistent: firms with high controversy exposure face return penalties, particularly when market uncertainty increases.

This study's key strength lies in its integration of methodological clarity (disaggregated ESG betas, sector-neutral sorting, and rolling/Kalman estimation) with regime-aware panel modelling. The fixed-effects specification demonstrates superior robustness and model fit. Unlike most studies, which rely on composite ESG scores, this study demonstrates that component-level exposures are both interpretable and empirically stable, particularly under macrofinancial stress.

For policy and asset managers, the results suggest that ESG premiums intensify as policy support and uncertainty increase. This finding reinforces the importance of considering the macro-institutional context in ESG integration. Climate risk exposure (carbon beta) is not always priced, unless it interacts with regulatory shifts, highlighting the need for dynamic conditional models. Similarly, reputational risk may require contextual triggers (e.g., regulatory or media shocks) to manifest in returns.

From a modeling perspective, this study contributes to the transition from static linear models toward conditional factor-decomposed structures. Future directions include interacting ESG betas with investor types, policy constraints, or sector characteristics, and extensions identified for further empirical development.

Conclusion

This study shows that ESG factors are not priced uniformly but instead exhibit conditional and component-specific return premia in European equity markets. Using a two-stage Fama–MacBeth framework and dynamic beta estimation, the results demonstrate that disaggregated ESG exposures are significantly priced, particularly during periods of systemic stress and regulatory transition. By contrast, carbon intensity and reputational risk, proxied through controversy exposure, are not consistently priced under baseline conditions but display sensitivity to regime dynamics.

These findings contribute to the ongoing debates over the theoretical role of ESG in asset pricing, supporting the perspective that ESG factors operate as both priced risk and investor preference channels contingent on the market context. The results caution against the use of aggregate ESG scores in pricing models, as they may obscure the distinct and time-varying influence of ESG subcomponents. Practically, the evidence suggests that investors may increasingly favor ESG-aligned firms during periods of heightened uncertainty or policy changes, reinforcing the need for asset managers to adopt context-sensitive ESG integration strategies. The emergence of a conditional carbon penalty also underscores the growing materiality of climate transition risk under regulatory regimes such as the EU Green Deal and Corporate Sustainability Reporting Directive (CSRD). These findings reinforce the relevance of EU sustainable finance legislation – particularly the CSRD and SFDR – in shaping market recognition of ESG and carbon-related risks.

Future research should extend this framework by incorporating investor segmentation, nonlinear preferences, and policy-specific carbon-pricing mechanisms. As ESG disclosures become more standardized under the CSRD and related frameworks, broader and more granular datasets – spanning additional countries, sectors, and rating providers – will enable more robust and generalizable ESG pricing analyses. Expanding the sample beyond the ESG index constituents and increasing the number of factor portfolios could further validate these findings, whereas the integration of multiple ESG data sources would allow the testing of rating divergence and institutional effects. This study provides a replicable foundation for such advances.

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