Politická ekonomie 2025

Volume 73 (4)
https://doi.org/10.18267/j.polek.1460
Open Access

PRAGUE UNIVERSITY OF ECONOMICS AND BUSINESS

Reimagining Recovery: Macroeconomic Power of Energy Efficiency in Crisis Times

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Abstract

This paper examines the profound effects of the COVID-19 pandemic on South Korean society, particularly focusing on the economic repercussions of a shock in energy use efficiency from Q1 2020 to Q3 2023. Employing advanced Bayesian estimation and impulse response function methods, the study reveals that enhanced energy use efficiency significantly boosts key economic metrics, including output, consumption, employment, energy use, real wages and investment. Additionally, an increase in real money holdings and a decrease in both deposit and loan interest rates are observed. The analysis further explores the impact of monetary policy adjustments made by South Korea to mitigate the economic challenges posed by the pandemic. Our results indicate that these policy shifts temporarily elevate the aforementioned economic variables and raise deposit and loan interest rates, despite a concurrent reduction in real wages. The findings provide critical insights for policy formulation and economic recovery strategies in the context of global health crises.

Keywords: COVID-19 pandemic, energy use efficiency, Bayesian estimation, monetary policy, economic recovery

JEL Classification: E12, F62, Z18

1. Introduction

The COVID-19 pandemic caused unprecedented disruptions across the global economy, profoundly affecting various sectors and leading to significant changes in economic activities and energy consumption patterns. The pandemic-induced economic slowdown resulted in reduced industrial output, disrupted supply chains and altered consumer behaviour, thereby influencing energy demand and usage globally. During the pandemic, many countries implemented lockdowns and restrictive measures to contain the virus, which led to a dramatic reduction in energy consumption, particularly in the transportation and industrial sectors. According to the International Energy Agency (IEA), global energy demand declined by approximately 4% in 2020, marking the largest annual decline since World War II. This decrease in energy use not only affected global energy markets but also highlighted the vulnerabilities and dependencies of economies on energy consumption. Simultaneously, the pandemic accelerated the adoption of energy-efficient technologies and practices as businesses and governments sought to reduce operating costs and enhance sustainability. The shift towards remote working, increased reliance on digital infrastructure and the need for resilient and sustainable energy systems became more pronounced. These changes underscored the critical role of energy efficiency in building economic resilience and achieving long-term sustainability goals.

The unprecedented disruptions in the global economy caused by the COVID-19 pandemic led countries to reassess their economic strategies and policies. South Korea, recognized for its strong economy and technological innovation, has encountered significant challenges in this context. The impact of the pandemic extended beyond public health and everyday life, significantly affecting the country's economic performance. Recent scholarly works emphasize the critical role of energy efficiency in bolstering economic resilience during crises. For example, Lee and Woo (2020) and Kim and Bae (2022) highlighted how adopting energy-efficient practices in various industries can alleviate economic downturns by cutting operating costs and promoting sustainability. Similarly, Tian *et al.* (2022), Mišík and Nosko (2023), Zhang *et al.* (2023) and Smol (2022) have investigated the link between energy efficiency and post-pandemic economic recovery, proposing that efficient energy use in both the manufacturing and domestic sectors could expedite economic recovery. These studies underscore the role of energy efficiency in reinforcing economic stability. Additionally, research by Gribkova and Milshina (2022), Wu *et al.* (2024) and Dabija *et al.* (2022) has revealed a shift in consumer preferences towards energy-efficient products amid the pandemic, signalling changes in market dynamics that could alter production patterns and economic indicators. Furthermore, Choi *et al.* (2023), Lee and Lee (2023), Choi and Koo (2023) and Kim (2022) have examined how this consumer shift, combined with governmental incentives for energy-efficient technologies, affected key sectors of South Korea's economy, such as electronics and automotive, which are crucial for its economic expansion. The significance of government policies in boosting energy efficiency and their effect on economic indicators cannot be overstated. Sassi and Frassineti (2021), Park and Chung (2021), Joo *et al.* (2023), Jeong and Kim (2021) and Bang *et al.* (2021) have noted that during the pandemic, South Korea's strategic interventions in the energy sector were pivotal to economic stabilization. These measures included subsidies for energy-efficient devices and tax incentives for investments in green energy, which not only aided businesses but also stimulated consumer expenditure. Additionally, the relationship between energy efficiency and South Korea's financial markets has garnered attention. Research by Moon and Min (2020), Zhao *et al.* (2022), Wenlong *et al.* (2022), Liu *et al.* (2022) and Li *et al.* (2023) has demonstrated that enhancements in energy efficiency contributed to financial market stability by lowering business operating costs, thus positively influencing the stock market and reinforcing investor confidence.

Overall, the current literature indicates that energy efficiency has played an essential role in shaping South Korea's economic manoeuvring in response to the COVID-19 pandemic, affecting a range of economic indicators from consumer spending to production and from financial markets to overall economic steadiness. This study seeks to expand upon these findings by providing a comprehensive analysis of how changes in energy efficiency have affected South Korea's economic indicators amidst the COVID-19 pandemic challenges. In this context, understanding the interplay between energy efficiency, economic stability and monetary policy becomes crucial. By employing a dynamic stochastic general equilibrium (DSGE) model, this research aims to provide empirical insights into the effects of energy efficiency on key economic indicators such as output, consumption, employment and financial stability. This study is timely and relevant, offering valuable implications for policymakers striving to foster economic recovery and resilience in the face of ongoing and future global crises. By exploring the dynamic interactions between energy efficiency and monetary policy, the research contributes to the broader understanding of sustainable development and economic policy formulation in times of significant disruptions.

This paper presents several significant contributions to understanding economic dynamics during the COVID-19 pandemic, with a particular focus on South Korea. These contributions address the interconnections between energy efficiency, monetary policy and macroeconomic stability, providing valuable insights for both theoretical and practical applications. Firstly, the study empirically demonstrates how improvements in energy use efficiency positively influence critical economic indicators such as output, consumption and employment. These findings underscore the potential for energy efficiency enhancements to act as catalysts for economic growth and stability, offering actionable insights for policymakers focused on sustainable development and economic resilience. Secondly, the research explores the complex relationship between energy efficiency and financial metrics, specifically real money holdings and interest rates. The observed decrease in deposit and loan interest rates associated with improved energy efficiency provides a novel perspective on how energy policies can affect financial stability and monetary policy. This contribution enriches the fields of monetary economics and financial market studies by linking energy efficiency initiatives to broader economic outcomes. Thirdly, the study illuminates the immediate effects of monetary policy adjustments during a global crisis such as the COVID-19 pandemic. It reveals that monetary policy shocks can temporarily boost economic indicators, including output and consumption, while also highlighting a potential short-term reduction in real wages. This nuanced analysis offers a comprehensive understanding of the trade-offs involved in monetary policy manoeuvres, providing valuable guidance for central banks and economic policymakers. Fourthly, by employing advanced methods such as Bayesian estimation and impulse response functions, this paper sets a high standard for future studies examining economic phenomena. The robust empirical techniques utilized not only ensure the reliability of the findings but also demonstrate the effectiveness of these methods in capturing the dynamic interactions between energy efficiency, monetary policy and macroeconomic variables during periods of significant disruption. Finally, by providing detailed empirical evidence on the benefits of energy efficiency improvements, this research supports the formulation of policies aimed at achieving sustainable development goals. It underscores the importance of integrating energy efficiency measures into broader economic strategies to enhance resilience against future crises, making a compelling case for energy efficiency as a cornerstone of sustainable economic policy. In summary, this study offers a comprehensive and nuanced examination of the interaction between energy efficiency and monetary policy and their influence on macroeconomic stability during the COVID-19 pandemic. These contributions advance theoretical understanding and provide practical insights for policymakers, thereby addressing the critical need for innovative and evidence-based approaches to economic policy in times of crisis.

The remaining sections of this article are organized as follows: Section 2 conducts a review of the literature relevant to the subject matter; Section 3 introduces the theoretical model employed in our analysis; Section 4 analyses the results and discusses their broader implications; and finally, Section 5 summarizes the main findings, drawing conclusions from the research.

2. Literature Review

The COVID-19 pandemic has catalysed significant shifts across various economic sectors, primarily driven by the adoption of energy-efficient practices and technologies. Research by Hermundsdottir *et al.* (2022), Zhang *et al.* (2022), Marimuthu *et al.* (2022), Ling *et al.* (2022) and Kazancoglu *et al.* (2023) underscores the beneficial impact of energy efficiency on industrial output, demonstrating that businesses integrating green technologies not only coped with pandemic challenges but sometimes even enhanced their production. This trend highlights the resilience and adaptability of sectors that have embedded energy efficiency into their core operations. On the consumer front, studies by Axon *et al.* (2023), Matiiuk and Liobikienė (2023), Brown *et al.* (2023), Rozhkov *et al.* (2023) and Verhoef *et al.* (2023) reveal a significant shift towards energy-efficient products, reflecting a broader change in consumption patterns and environmental awareness during the pandemic. This shift is attributed to increased recognition of environmental issues and the long-term economic benefits of energy-efficient products.

The employment landscape, analysed by Karakosta *et al.* (2021), Strielkowski *et al.* (2021) and Rokicki *et al.* (2022), presents a dual scenario where energy efficiency promotes job growth in green technology sectors but results in job losses in traditional industries slower to adapt. This dichotomy underscores the necessity for targeted workforce training and policy interventions to facilitate the transition of the labour force from declining sectors to emerging ones. In terms of overall energy consumption, studies by Kuzemko *et al.* (2020) and Arsad *et al.* (2023) observe a decline in both commercial and residential energy use, attributed to enhanced energy efficiency, pandemic-induced operational changes and reduced industrial activities during lockdowns. These trends not only mirror the immediate effects of the pandemic on energy consumption but also suggest a potential enduring shift towards more sustainable energy practices. Collectively, these studies provide a detailed narrative of how the pandemic has reshaped industries, consumer behaviour, employment and energy consumption. They offer valuable insights into the role of energy efficiency in fostering economic resilience and suggest pathways for sustainable post-pandemic economic growth.

Research into the economic repercussions of improved energy efficiency during the COVID-19 pandemic reveals a diverse and evolving picture. Insights from Spangenberg and Kurz (2023), Vîrjan *et al.* (2023), Karda *et al.* (2023) and Ghannouchi (2023) highlight varying impacts on real wages across different industries. Sectors that adopted energy-efficient technologies saw wage increases due to higher demand for skilled labour, while less adaptive sectors experienced wage stagnation. This disparity underscores the need for targeted policy measures to address the unequal distribution of the benefits of energy efficiency. On the investment front, research by Li *et al.* (2022), Saqib and Dincă (2023), Wan *et al.* (2022), Gan *et al.* (2020) and Razzaq *et al.* (2023) points to a significant trend towards sustainable and energy-efficient initiatives. This trend is driven by environmental considerations and the recognition of the long-term economic advantages of sustainable practices. The growing interest in green investments reflects a shift in the overall investment paradigm, embracing the economic potential of sustainability. The impact of energy efficiency on financial markets, particularly concerning real money holdings and interest rates, is complex and nuanced. Studies by Xin and Jiang (2023), Liu and Lee (2022), Carrasco-Gallego (2020), Dunz *et al.* (2021) and Chen *et al.* (2021) suggest that energy efficiency enhancements contribute to financial market stability, though their influence varies depending on broader economic conditions and specific pandemic responses. This complexity is further explored in research by Jiang *et al.* (2021), Zakeri *et al.* (2022), Hepburn *et al.* (2020), Zhang *et al.* (2023a), Wang *et al.* (2022), Shehabi (2022), Kikstra *et al.* (2021), Ekinci *et al.* (2022) and Apergis *et al.* (2023), who have examined the interaction between energy efficiency and various economic and monetary policies during the pandemic. Overall, this body of research indicates that the move towards energy efficiency generally promotes positive outcomes in output, consumption, employment and investment. However, its effects on wages, monetary holdings and interest rates are intricate, necessitating a comprehensive approach to fully understand these dynamics. Future research should adopt an integrated perspective, considering how energy efficiency intersects with economic resilience and the broader socio-economic context shaped by the pandemic.

Summarizing the findings, studying the impact of energy efficiency changes on South Korea's economic indicators during the COVID-19 pandemic is crucial for understanding and addressing economic dynamics in a global crisis. This study empirically demonstrates that improvements in energy efficiency positively influence key economic indicators, such as output, consumption and employment, providing policymakers with tools to foster growth and stability. It also explores the interplay between energy efficiency and financial factors such as real money holdings and interest rates, enriching the fields of monetary policy and financial market studies. Lastly, the study highlights the short-term impacts of monetary policy shifts during the crisis, offering insights into their effects. Collectively, these contributions enhance our understanding of how energy efficiency, monetary policy and macroeconomic elements interact during disruptions, aiding in the planning of sustainable post-pandemic economic development.

3 Theoretical Framework

3.1 Households

Expanding on the studies by He and Wang (2022), Wang and He (2023) and He (2023), we argue that the economic framework in question represents a typical household. We define the utility function as follows:

$$U = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+n}}{1+n} + \frac{\left(\frac{M_t}{P_t}\right)^{1-\rho}}{1-\rho} \right] \tag{1}$$

In Equation (1), U stands for the utility function, E represents the expectation mechanism, β is the discount factor, C refers to consumption, σ indicates the elasticity of consumption to relative risk aversion, L signifies labour, n is the inverse elasticity of labour supply, M corresponds to nominal monetary assets, P is the price level and ρ captures the reciprocal elasticity of the real monetary balance. Additionally, we outline the budget constraint that a standard household typically encounters as follows:

$$C_t + K_{t+1} + \frac{M_t}{P_t} - \frac{M_{t-1}}{P_t} + \frac{B_t}{P_t} + \frac{B_{t-1}}{P_t} R_{t-1}^b = W_t L_t + R_t^k K_t + (1-\delta) K_t + D_t \tag{2}$$

In Equation (2), K is used to symbolize capital, B refers to bonds, R^b represents the interest rate on deposits, W indicates wages, R^k is associated with capital rental, δ denotes the depreciation rate and D identifies dividends. Furthermore, our analysis draws upon the studies by Hohberger *et al.* (2019), Li (2022), Sadeghi *et al.* (2022), Xie (2021) and Zarei *et al.* (2019) to explore the relationship between lending rates and deposit interest. The findings are presented as follows:

$$P_t W_t L_t = \xi_t \zeta \left(\frac{Y_t}{\tilde{Y}} \right)^{\tau} B_t \tag{3}$$

In Equation (3), ξ corresponds to shocks in the lending interest rate, ζ is the equilibrium loan-deposit ratio, Y represents output, $\tilde{Y}$ is the equilibrium output value and τ indicates how total loans respond to economic shifts. Drawing insights from the methods of Hohberger *et al.* (2019), Benati (2023), Chang *et al.* (2021), Leni Anguyo *et al.* (2020) and Binder and Sekkel (2023), we incorporate the concept of labour brokers within the economic framework. These brokers source diverse labour types from households and supply them to factories, essentially acting as intermediaries. In setting wages, households employ the Calvo wage setting approach, akin to Górajski and Kuchta (2023), Čapek *et al.* (2023), Iania *et al.* (2023) and Demirok *et al.* (2023), mirroring the pricing strategies of intermediate producers. This model assumes that households adjust nominal wages optimally only upon receiving a stochastic "wage adjustment prompt". The frequency of receiving these prompts per period is denoted by $1 - \psi$. When a prompt is received, the optimal nominal wage is adjusted to $\widetilde{W}_t$, while for others, wage adjustments align with the prior year's inflation rate, denoted as $W_t^n = \pi_{t-1} W_{t-1}^n$. In achieving equilibrium among equivalent producers, wages are calculated using the following formula:

$$W_t^n = \left[(1-\psi)\left(\widetilde{W}_t\right)^{1-\nu_t} + \psi\left(\pi_{t-1} W_{t-1}^n\right)^{1-\nu_t} \right]^{\frac{1}{1-\nu_t}} \tag{4}$$

In Equation (4), ψ is the likelihood of missing a wage adjustment signal, $\widetilde{W}$ stands for the ideal wage setting, W^n is the current nominal wage, π represents inflation and v indicates the responsiveness of labour demand to wage changes. We suppose a that typical household (j) does not receive the wage adjustment signal, its wage during the period $t + s$ is determined as W_{t+s}^n. For instances where $s$exceeds 1, the wage is set at $W_t^n = \pi_t \pi_{t+1} \ldots \pi_{t+s-1} \widetilde{W}_t$. Conversely, if s equals one, the wage is established as $W_{t+s}^n = \widetilde{W}_t$. By integrating Equations (1) through (4), we derive the first-order condition for a typical household in the following framework.

$$E_t \sum_{s=0}^{\infty} (\beta\psi)^s \left[L_{t+s} C_{t+s}^{1-\sigma} \left(\frac{W_{t+s}^n}{P_{t+s}} - \frac{\nu_{t+s}}{1-\nu_{t+s}} \frac{L_{t+s}^{1+n}}{C_{t+s}^{1-\sigma}} \right) \right] = 0 \tag{5}$$

3.2 Firms

Building on the findings of Huynh (2016), He and Lee (2022) and Punzi (2019), the business landscape is categorized into two separate types of firms. The first type is tasked with producing the end product, while the second type specializes in manufacturing goods at various intermediate stages. This model presupposes a series of ongoing intermediate firms operating within the economy. In an environment of perfect competition, the depiction of the final product is as follows:

$$Y_t = \left(\int_0^1 Y_{i,t}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{6}$$

In Equation (6), Y represents the final product, Y_i refers to the intermediate goods and η signifies the elasticity of substitution among these intermediate goods. Given that the producer of the final product operates on a fully competitive market, their primary objective is to maximize profits, taking into account both the price of the final and intermediate products. A demonstration of this concept is outlined as follows:

$$\max_{Y_{i,t}} \; P_t Y_t - \int_0^1 P_{i,t} Y_{i,t} di \tag{7}$$

In Equation (7), P_i is assigned to represent the pricing of intermediate goods. Following the logic of Equation (7), the quantity demanded for the output produced by the i-th intermediate goods manufacturer is identified as $Y_{i,\,t} = (P_{i,\,t} \,/\, P_t)^{1/\eta}$. Moreover, in environments marked by monopolistic competition, the producers of these intermediate products adjust and streamline their processes in the following manner:

$$\min \; R_t^o W_t L_{i,t} + P_t^{ec} EC_{i,t} + R_i^k K_{i,t} \tag{8}$$

In Equation (8), R^o is used to indicate the aggregate lending interest rate, P^{ec} corresponds to the price of energy and EC signifies energy itself. Drawing upon the research of Liu *et al.* (2015), Hsiao *et al.* (2023), Xiao *et al.* (2023), Fasani *et al.* (2023), Baas and Belke (2023) and Zhang *et al.* (2023b), the shock to energy prices is denoted as $\log \frac{P_t^{ec}}{\tilde{P}^{ec}} = \rho_{ec} \log \frac{P_{t-1}^{ec}}{\tilde{P}^{ec}} + \log \frac{\omega_t^{ec}}{\tilde{\omega}^{ec}} + \rho_{\omega^{ec}} \log \frac{\omega_{t-1}^{ec}}{\tilde{\omega}^{ec}}$. Additionally, we provide an overview of the financial restrictions typically encountered by a standard manufacturer of intermediate products:

$$Y_{i,t} = A_t K_{i,t}^{\alpha} L_{i,t}^{\varpi} \left(\omega_t EC_{i,t} \right)^{1-\alpha-\varpi} \tag{9}$$

In Equation (9), A is defined as the measure of productivity, reflecting the overall knowledge and techniques of production prevalent in the economy. α captures how production levels change relative to capital input, ϖ reflects changes in production relative to labour input and ω is indicative of shifts in energy use efficiency. Drawing on insights from Kiarsi (2023), Delpachitra *et al.* (2020), Born and Pfeifer (2020), Lozej *et al.* (2023), Cho *et al.* (2021) and Chan (2020), it is posited that the producer of intermediate goods sets prices using the Calvo pricing strategy, aiming to maximize real discounted profits. In each time period, a fraction $1 - \Phi$ of these producers adjusts their prices to reach the optimal price p. In contrast, the remaining producers adjust their prices based on the previous year's inflation rate, labelled $\pi_{t-1} = P_{t-1} / P_{t-2}$. The degree of this indexation is represented by $P_{i,t} = P_{i,t-1}$ and the utility function is structured to maximize real discounted profits.

$$\max_{\dot{P}_t} E_t \sum_{j=0}^{\infty} \left(\beta\phi\right)^j \lambda_{t+j} \left[Y_{i,t+j} \left(\prod_{m=1}^{j} \pi_{t-1}^{\varphi_p} \frac{\dot{P}_t}{P_{t+j}} - MC_{t+j} \right) \right] \tag{10}$$

In Equation (10), λ is assigned as the Lagrange multiplier, MC represents the marginal cost and Φ signifies the likelihood of missing a signal. The budget constraint is articulated as follows:

$$Y_{i,t+j} = \left(\prod_{m=1}^{j} \pi_{t-1}^{\varphi_p} \frac{\dot{P}_t}{P_{t+j}} \right)^{\frac{1}{\varsigma}} Y_{t+j} \tag{11}$$

In Equation (11), ς is used to represent the elasticity of substitution among intermediate goods. The first-order condition derived from this is outlined as follows:

$$\dot{P}_t = \frac{\varsigma}{\varsigma - 1} \frac{E_t \sum_{j=0}^{\infty} \left(\beta\phi\right)^j \lambda_{t+j} Y_{i,t+j} P_{i,t+j} MC_{t+j}]}{E_t \sum_{j=0}^{\infty} \left(\beta\phi\right)^j \lambda_{t+j} \prod_{m=1}^{j} \pi_{t-1}^{\varphi_p} Y_{i,t+j}} \tag{12}$$

Consequently, the aggregate price level is determined as follows:

$$P_t = \left[\left(1-\phi\right) \dot{P}_t^{\,1-\varsigma} + \phi \left(\pi_{t-1}^{\varphi_p} P_{t-1} \right)^{1-\varsigma} \right]^{\frac{1}{1-\varsigma}} \tag{13}$$

3.3 Central banks

Drawing on the research by Hirose (2020), Iiboshi *et al.* (2022), Fernández-Villaverde and Guerrón-Quintana (2021), Costa (2019), Storm (2021) and Sergi (2020), it is hypothesized that the monetary authority employs comprehensive interest rate policies to manage both the deposit interest rate and the overall output.

$$\log \frac{R_t^b}{\bar{R}^b} = \iota \log \frac{R_{t-1}^b}{\bar{R}^b} + \left(1-\iota\right) \left[\rho_\pi \log \frac{\pi_t}{\tilde{\pi}} + \rho_y \log \frac{Y_t}{\tilde{Y}} \right] + \log \frac{\omega_t^r}{\tilde{\omega}^r}) \tag{14}$$

In Equation (14), ι is defined as the coefficient for interest rate smoothing, ρ_π refers to the coefficient measuring the interest rate's response to inflation, ρ_y indicates how the interest rate reacts to changes in output and ω^r represents the shock to monetary policy. Furthermore, $\widetilde{R}^b$ is the equilibrium value of the deposit interest rate, $\tilde{\pi}$ is the rate of inflation and $\widetilde{Y}$ denotes the equilibrium output level.

3.4 Market clearing condition

The condition for equilibrium on the market is expressed as follows:

$$Y_t = C_t + K_{t+1} - (1-\delta)K_t + P_t^{ec}EC_t \tag{15}$$

4. Results

4.1 Parameters

The parameters of this study were sourced from two primary channels: authoritative existing literature from South Korea and Bayesian estimations derived from South Korean data. In terms of parameter calibration, as per He (2022), the production elasticity of capital is 0.43 and as per Kang and Suh (2017), the production elasticity of labour is 0.3. According to Lee and Song (2015), the discount factor is 0.980 and according to Choi and Hur (2015), the depreciation rate is 0.025. Pontines (2021) indicated a value of 1.150 for the responsiveness of total loans to economic shifts. The equilibrium loan-deposit ratio, following Kim (2022), is 0.560. Hur and Lee (2017) indicated that the probability of missing a price signal is 0.75 and Iwasaki *et al.* (2021) suggested that the probability of missing a wage signal is also 0.75. The degree of price indexation, according to Hur and Rhee (2020), is 0.3. For the Bayesian estimation part, this article utilizes quarterly data from the Korean GDP and inflation spanning from Q1 2020 to Q3 2023, a period inclusive of the COVID-19 outbreak, which justifies its selection for the analysis. Following the methodology of Hwang (2009), Taylor and Lee (2014) and Han and Hur (2020), the Hodrick–Prescott filter is applied to isolate the cyclical components from the GDP and inflation trends. Table 1 presents the outcomes of the Bayesian estimation process.

Table 1: Results of Bayesian estimation

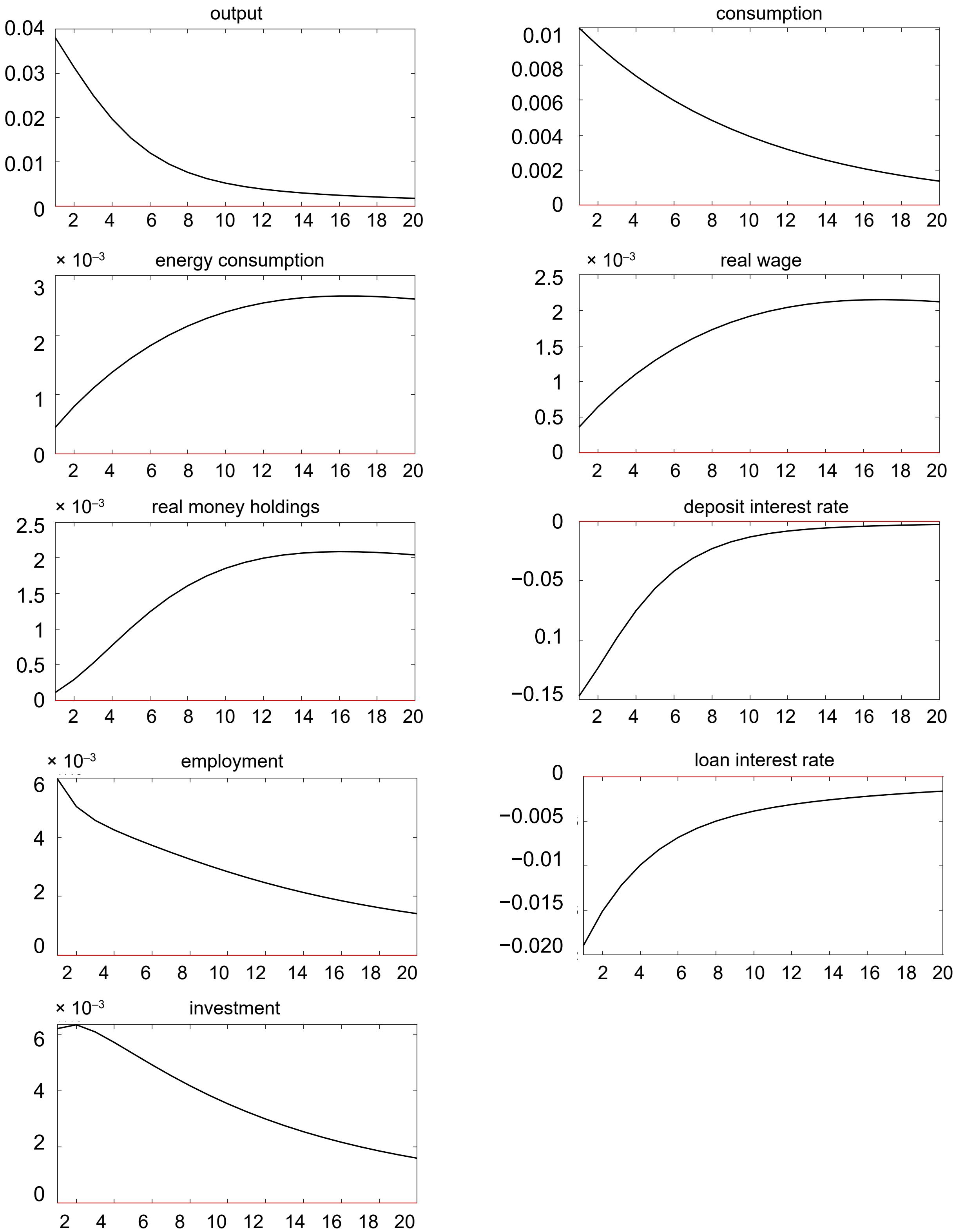
Parameter	Definition	Prior distribution	Posterior mean	Confidence interval
σ	Relative risk aversion elasticity of consumption	Gamma [1, 0.25]	0.921	[0.901, 0.928]
n	Reciprocal elasticity of labour supply	Gamma [2, 0.25]	4.334	[3.214, 4.822]
ϱ	Elastic reciprocal of real balance	Gamma [2.5, 0.25]	2.438	[1.948, 2.816]
ι	Smoothing coefficient of interest rate	Beta [0.4, 0.3]	0.907	[0.745, 0.964]
ρ_π	Reaction coefficient of interest rate rules to inflation	Gamma [1.75, 0.25]	1.769	[1.742, 1.827]
ρ_y	Reaction coefficient of interest rate rules to output	Gamma [0.2, 0.1]	0.128	[0.078, 0.182]
ρ_{ec}	Autoregressive parameter of energy price shock	Beta [0.5, 0.2]	0.613	[0.523, 0.659]
ρ_ω	Autoregressive parameter of energy use efficiency shock	Beta [0.5, 0.2]	0.487	[0.186, 0.831]
$\rho_\omega^{\ r}$	Autoregressive parameter of monetary policy shock	Beta [0.5, 0.2]	0.78	[0.712,0.893]
σ_{ec}	Standard error of energy price shock	Inverse-gamma [0.01, inf]	0.074	[0.064, 0.085]
σ_ω	Standard error of energy use efficiency shock	Inverse-gamma [0.01, inf]	1.272	[1.123, 1.419]
$\sigma_\omega^{\ r}$	Standard error of monetary policy shock	Inverse-gamma [0.01, inf]	0.984	[0.872, 1.091]

Source: Statistic Korea data (2024)

4.2 Influence of enhanced energy efficiency on macroeconomic indicators in Korea during COVID-19 pandemic

Enhancing the efficiency of energy utilization could play a crucial role in lessening the impact of the COVID-19 pandemic on the stability and performance of South Korea's major economic indicators. In light of this, the focus of this segment is to examine and understand the repercussions of improved energy use efficiency on the key economic variables of South Korea during the challenging times of the COVID-19 health crisis. This analysis aims to unravel the relationship between energy efficiency and economic resilience in the face of a global pandemic. The results of this detailed investigation are illustrated in Figure 1, which provides a visual representation of the observed effects and trends during this tumultuous period.

Figure 1: Simulation of energy efficiency impact on Korean economy during COVID-19



Source: Author's own elaboration

Figure 1 demonstrates the simulated effects of enhanced energy efficiency on several macroeconomic indicators in South Korea during the COVID-19 pandemic. The key variables analysed include output, consumption, employment, energy use, real wages, investment, real money holdings and interest rates on deposits and loans.

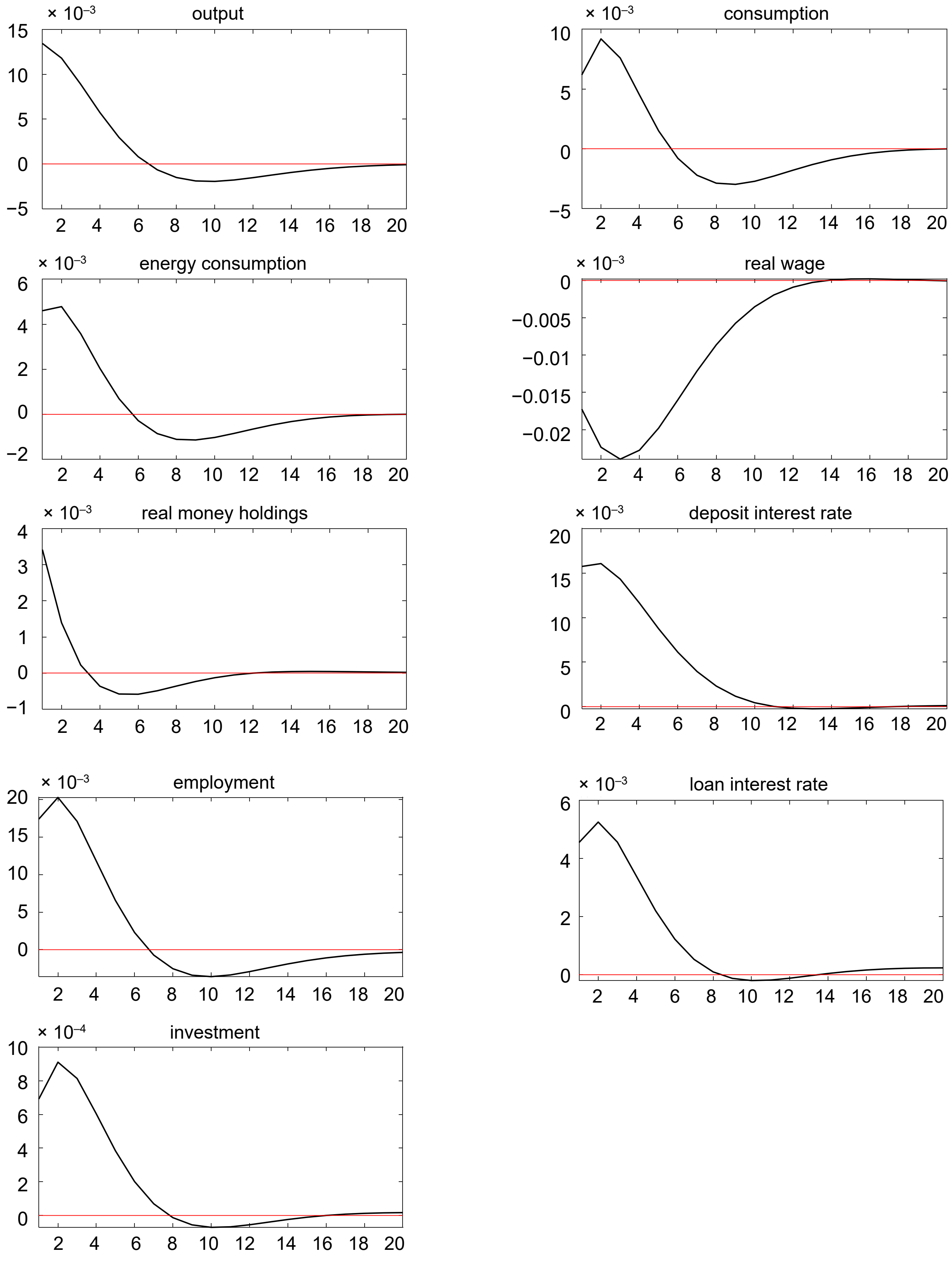
The simulation reveals a positive correlation between improved energy efficiency and increases in both output and consumption. This result is consistent with the theoretical framework of endogenous growth theory, which posits that technological advancements and efficiency improvements can stimulate economic growth by increasing productivity and reducing costs (Chen *et al.*, 2021; Dabbous and Tarhini, 2021; Yang *et al.*, 2023). Studies by Kang and Lee (2016), Kim and Brown (2019) and Hille and Lambernd (2020) also support this finding, showing significant gains in industrial output and consumer spending resulting from energy efficiency improvements in South Korea. The results indicate an increase in employment and real wages with the enhancement of energy efficiency. This finding aligns with those of Dell'Anna (2021b) and García-Quevedo and Jové-Llopis (2021), who suggested that investments in energy efficiency can create jobs and elevate wage levels by boosting demand for labour in green technology sectors. However, the study also reveals a nuanced effect, where real wages initially increase but subsequently decline following monetary policy adjustments, indicating a potential short-term trade-off between employment gains and wage adjustments. This complexity is further explored in the works of Petrosky-Nadeau and Wasmer (2015) and Cacciatore and Fiori (2016), who discussed the dynamic interplay between labour market adjustments and macroeconomic policies. The simulation results suggest that energy use efficiency leads to a reduction in overall energy consumption, coupled with an increase in business investment. This outcome is supported by Henriques and Catarino (2016) and Adisorn *et al.* (2020), who showed that energy-efficient practices reduce operating costs, thereby freeing up capital for further investments. Additionally, Polzin *et al.* (2017) and Fowlie and Meeks (2021) found that such efficiency improvements can stabilize financial markets and create a conducive environment for investment.

Following improvements in energy efficiency, an increase in real money holdings and a decrease in deposit and loan interest rates are observed. These findings are consistent with the liquidity preference theory (Demiralp *et al.*, 2021; Syarifuddin and Bakhtiar, 2022), which posits that lower interest rates encourage holding money rather than saving it. Similarly, Wang and Lee (2023) indicated that improved energy efficiency can lead to lower borrowing costs and increased liquidity in the economy. Our results show both convergence with and divergence from existing literature. While the positive impacts of energy efficiency on output, consumption and employment are well documented (Brockway *et al.*, 2021; Tang and Jefferson, 2024), the findings also highlight unique short-term dynamics, such as the temporary decline in real wages following monetary policy adjustments. This observation adds a new dimension to the existing discourse, suggesting that while energy efficiency enhances overall economic resilience, the distributional impacts on wages necessitate careful policy consideration. Moreover, the study underscores the significant role of monetary policy in moderating the effects of energy efficiency improvements. This aspect is partially addressed in the literature by Chan (2020) and Khan *et al.* (2023), but our findings provide a more detailed empirical analysis of the short-term trade-offs involved. By integrating these insights and comparisons with existing literature, we aim to bolster its robustness and credibility. A detailed analysis of Figure 1, supported by relevant macroeconomic theories and empirical studies, offers a comprehensive understanding of the impact of energy efficiency on South Korea's economy during the COVID-19 pandemic.

4.3 Influence of monetary policy on Korean macroeconomic indicators during COVID-19 pandemic

The conventional tools of monetary policy have demonstrated their potential for effectively addressing the fluctuations in South Korea's macroeconomic landscape, particularly those induced by the COVID-19 pandemic. Consequently, this subsection is dedicated to an analysis of how monetary policy has influenced vital macroeconomic indicators in South Korea throughout the duration of the pandemic. We delve into the nuances of these impacts, exploring the interplay between monetary policy adjustments and economic variables during this period. The findings of this in-depth examination are depicted and elaborated upon in Figure 2.

Figure 2: Simulation of monetary policy impact on Korean economy during COVID-19



Source: Author's own elaboration

Figure 2 presents the simulated impact of monetary policy adjustments on various macroeconomic indicators in South Korea during the COVID-19 pandemic. The key variables analysed include output, consumption, employment, energy use, real wages, investment, real money holdings and interest rates on deposits and loans. The simulation results indicate that monetary policy adjustments lead to a significant increase in output and consumption. This finding is consistent with the Keynesian framework, which posits that expansionary monetary policy can stimulate aggregate demand by lowering interest rates and increasing the money supply (Belongia and Ireland, 2015; Bottero *et al.* (2022). Empirical studies by Pyun and Rhee (2015) and Choi *et al.* (2017) corroborate this result, demonstrating that South Korea's monetary policy responses during economic downturns have effectively boosted domestic demand and output. An increase in employment is observed following monetary policy adjustments, aligning with the findings of Rostamkalaei and Freel (2016) and Bravo-Biosca *et al.* (2016), who argued that lower interest rates reduce borrowing costs, thereby encouraging business expansion and increased hiring. However, the simulation also reveals a temporary decrease in real wages, highlighting a potential short-term trade-off between employment gains and wage levels. This phenomenon is discussed in the literature by Rudebusch and Williams (2016) and Cronert (2019), who have suggested that while expansionary monetary policy can reduce unemployment, it may also exert downward pressure on wages due to increased labour supply. The simulation results show that monetary policy adjustments lead to increased energy use and business investment. This outcome is consistent with neoclassical investment theory, which posits that lower interest rates reduce the cost of capital, thereby encouraging firms to invest in new projects (Steffen, 2020; Xu, 2020). The study by Fan *et al.* (2023) supports this finding, indicating that South Korea's monetary policy adjustments during the COVID-19 pandemic facilitated increased investment in energy-intensive industries and infrastructure projects.

An increase in real money holdings and higher deposit and loan interest rates are observed following monetary policy adjustments. This result aligns with liquidity preference theory (Bayer *et al.*, 2019), which suggests that in times of economic uncertainty, individuals and businesses prefer to hold liquid assets. Research by Fry (2019) and Joo *et al.* (2024) supports this finding, showing that monetary policy adjustments in South Korea have led to a temporary increase in real money holdings as economic agents adjusted to new interest rate environments. The results of this study both converge with and diverge from existing literature. The positive impacts of monetary policy on output and consumption are well documented (Babecký *et al.*, 2018; Jesus *et al.*, 2020). However, the findings highlight the unique short-term dynamics of real wage adjustments, which are less frequently discussed in the context of monetary policy impacts during economic crises. This adds a new dimension to the existing discourse, suggesting that while monetary policy can drive economic recovery, the effects on wage distribution require careful consideration. Moreover, the study underscores the significant role of monetary policy in influencing energy use and investment. This aspect has been partially addressed in the literature by Angeloni *et al.* (2015) and Dafermos *et al.* (2018), but our findings provide a more detailed empirical analysis of the short-term trade-offs involved. By integrating these insights and comparisons with existing literature, we aim to enhance its robustness and credibility. A detailed analysis of Figure 2, supported by relevant macroeconomic theories and empirical studies, offers a comprehensive understanding of the impact of monetary policy on South Korea's economy during the COVID-19 pandemic. These findings provide valuable implications for policymakers aiming to balance economic recovery with wage stability and investment growth.

5. Conclusions

The COVID-19 pandemic has had a profound impact on all aspects of Korean society, leading to extensive disruptions. This study aimed to examine the impact of a shock in energy use efficiency on the volatility of South Korea's economic indicators during the pandemic. Utilizing Bayesian estimation and impulse response functions, we found that a positive shift in energy use efficiency is associated with increases in output, consumption, employment, energy consumption, real wages and investment, as well as an increase in real money holdings, while deposit and loan interest rates decrease. Additionally, to mitigate the impact of the pandemic on macroeconomic factors, South Korea has implemented monetary policy changes. Our findings indicate that a monetary policy shock leads to a short-term increase in output, consumption, employment, energy consumption, investment and real money holdings, coupled with a rise in deposit and loan interest rates, but a decrease in real wages.

Based on the empirical findings presented in this article, four policy implications emerge. Firstly, the rise in real wages and money holdings as a result of enhanced energy efficiency suggests that encouraging energy-saving practices could significantly improve the financial stability of households. At the same time, the observed decrease in real wages following monetary policy shocks indicates a need for additional financial support for households during such transitions. Policies such as tax breaks or direct subsidies could be instrumental, especially when adjusting monetary policies. Secondly, the positive correlation between improved energy use efficiency and higher output and investment suggests that firms would benefit from incentives to adopt energy-efficient technologies. This could involve government grants, tax benefits or low-interest financing for upgrades, potentially enhancing productivity and market competitiveness. Thirdly, while the government's monetary policy appears to affect key economic indicators in the short term, the associated rise in deposit and loan interest rates may increase borrowing costs for both businesses and consumers. It is crucial for the government to strike a balance between the immediate advantages of monetary policy shifts and their long-term effects on borrowing costs and overall economic growth. Lastly, the study underscores the need for integrated strategies that concurrently address energy efficiency and monetary policy. Aligning energy policies with monetary decisions can ensure that energy efficiency efforts complement broader economic goals. Additionally, vigilant monitoring of the effects of these policies on inflation and interest rates is essential for maintaining economic stability.

While this study presents valuable insights, it also acknowledges certain limitations, which in turn pave the way for further research in these areas. Firstly, the focus on South Korea's economy during the COVID-19 pandemic narrows its broader applicability. Future research could extend to a comparative analysis across various countries or under different economic scenarios, thereby enriching the understanding of how energy use efficiency, monetary policy and economic indicators interact globally. Secondly, our study emphasized the short-term implications of energy efficiency and monetary policy changes. Subsequent research could investigate the long-term effects of these factors, providing a more detailed view of their sustained impact on economic indicators. Thirdly, the reliance on Bayesian estimation and impulse response functions, while effective, comes with inherent limitations in data interpretation and prediction accuracy. Future studies might benefit from utilizing alternative econometric models or integrating more recent data, including post-pandemic figures, to further refine and substantiate these results. Lastly, this study offers a macroeconomic perspective but lacks a deep dive into sector-specific impacts. Future research could examine how changes in energy efficiency and monetary policy uniquely influence different sectors such as manufacturing, services or technology, offering valuable insights for targeted sectoral policies. Addressing these areas in future research will not only build upon our findings but also enhance our comprehension of the complex dynamics between energy policy, monetary measures and economic stability, especially in the wake of global challenges such as the COVID-19 pandemic.

Acknowledgement

Funding: There was no funding, either externally or internally, towards this study.

Conflicts of interest: The authors hereby declare that this article was not submitted no published elsewhere.

Data availability statement: The data presented in this study are available from the author upon request.

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