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The impact of u.s. monetary policy on carbon emissions: evidence from a TVP-VAR model with stochastic volatility

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Abstract

This study investigates the impact of U.S. monetary policy on carbon emissions using a Time-Varying Parameter Vector Autoregression (TVP-VAR) model with stochastic volatility, applied to quarterly data from 1973:Q1 to 2024:Q4. The findings indicate that a one percentage point increase in the interest rate leads to a reduction in emissions of 27.73 million metric tons (MMT) in 2001:Q1, 25.55 MMT in 2007:Q4, and 18.18 MMT in 2019:Q4, demonstrating a declining effect of monetary policy on emissions over time. These results highlight the evolving nature of monetary transmission and suggest that structural changes in the economy have weakened the environmental channel through which interest rate policy influences carbon outcomes. The study offers new insights for central banks seeking to align macroeconomic and climate goals.

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1. Introduction

In recent years, discussions on climate change have increasingly intersected with economic policy, particularly regarding the role of monetary policy in shaping environmental outcomes. Traditionally, monetary policy has been designed to control inflation, stabilize economic growth, and maintain employment, but its potential indirect effects on carbon emissions remain underexplored. The Federal Reserve's interest rate adjustments influence economic conditions through multiple transmission channels, affecting energy demand, production structures, and emissions levels. Given the growing urgency of climate change and sustainability goals, understanding the broader implications of monetary policy is essential. Even if monetary policy does not explicitly target environmental outcomes, its macroeconomic effects can have unintended yet quantifiable impacts on emissions, making it relevant for broader policy discussions.

While extensive literature explores the economic consequences of monetary policy, its environmental implications remain largely overlooked. Most research has concentrated on environmental regulations, carbon pricing, and renewable energy policies, leaving a gap in understanding how broader macroeconomic tools like monetary policy indirectly affect carbon emissions. For instance, policies such as Renewable Portfolio Standards (RPS) have been shown to improve grid reliability and reduce power interruptions, demonstrating how regulatory interventions shape environmental and infrastructure resilience (Singh et al., 2024). However, the role of monetary policy instruments—such as interest rate changes—on emissions remains less understood. This study bridges this gap by examining how the federal funds rate, a key short-term interest rate set by the Federal Reserve, impacts carbon emissions. By employing a Time-Varying Parameter Vector Autoregression (TVP-VAR) model with stochastic volatility, this research captures evolving economic conditions and assesses the dynamic effects of monetary policy on carbon emissions over different economic periods.

Monetary policy influences carbon emissions through multiple transmission channels, primarily linked to economic activity, production costs, and energy demand. First, the aggregate demand channel links interest rate changes to economic growth and industrial production, which impact energy consumption and emissions. Higher interest rates increase borrowing costs, reducing investment and industrial output, thereby lowering emissions, while lower interest rates stimulate economic activity and energy demand, increasing emissions. Second, the cost of capital channel suggests that tighter monetary policy raises financing costs, discouraging capital-intensive investments in carbon-heavy industries such as fossil fuel extraction, manufacturing, and construction. Third, the inflation and energy prices channel highlights how monetary tightening reduces inflation, which affects commodity and energy prices. Lower inflation can decrease fossil fuel prices, potentially increasing energy consumption, while higher inflation under expansionary policy may raise energy costs and discourage carbon-intensive activities. Fourth, the labor market channel reflects how contractionary monetary policy increases unemployment in energy-intensive sectors, leading to reduced household income and lower energy consumption, whereas expansionary policy promotes employment and emissions growth. Finally, the financial market channel illustrates how monetary policy influences speculation in commodity markets, particularly oil and gas investments, which in turn affects emissions trends. By incorporating these mechanisms, this study provides empirical evidence on how monetary policy shapes carbon emissions using a TVP-VAR model to capture these dynamic relationships.

Federal Reserve interest rate adjustments significantly impact economic variables such as inflation and economic growth, yet their influence on carbon emissions remains understudied. As central banks increasingly integrate climate considerations into economic policy discussions, understanding these transmission mechanisms becomes critical. Using quarterly data from 1973 to 2024, this study estimates the impulse response function (IRF) of carbon emissions to interest rate changes, focusing on three economic expansion periods. This approach captures economic cycles and provides insights into how monetary policy influences emissions trends. Even if the overall effect appears moderate, it underscores the broader, indirect role of monetary policy in shaping environmental outcomes, particularly as economies transition toward cleaner energy sources and reduced carbon dependency.

This growing recognition of monetary policy's environmental impact has sparked debate over whether central banks should adopt a more holistic approach to policymaking. In this study, a holistic approach does not imply shifting the Federal Reserve's core mandate of inflation control and economic stability but rather acknowledges the indirect environmental consequences of interest rate adjustments. Some interpretations suggest that central banks should explicitly incorporate climate-related risks into monetary frameworks, either through adjustments in interest rate policy or broader regulatory interventions such as green asset purchases or carbon-related financial stress testing (Dafermos et al., 2018). Others argue that monetary authorities should maintain a neutral stance on environmental issues, leaving climate policy to fiscal authorities while focusing solely on price stability and employment (Batten et al., 2020).

This study contributes to the ongoing debate by illustrating how monetary policy influences carbon emissions through its impact on economic activity. While the estimated effect of interest rate adjustments on emissions appears modest in percentage terms, it represents a substantial absolute reduction. In earlier years, a one percentage point increase in interest rates led to an estimated reduction of up to 27 million metric tons (MMT) of carbon emissions—equivalent to removing over 5.78 million[1] passenger vehicles from the road for a year (U.S. Environmental Protection Agency, 2023). However, this effect weakened to approximately 18 MMT by 2019. The diminishing impact over time can be attributed to both structural shifts—such as increased energy efficiency, financialization, and changes in industrial composition—and one-time shocks, including economic crises and policy interventions, which have further reduced the responsiveness of emissions to monetary policy. Events such as the 2008 financial crisis and the COVID-19 pandemic not only temporarily altered economic activity but also contributed to a long-term reduction in the effectiveness of interest rate adjustments on emissions. While monetary policy alone is not a primary instrument for emissions reduction, it plays a measurable role in shaping long-term emissions trends, underscoring the need for integrated macroeconomic and environmental policy considerations.

A substantial body of literature explores the connections between macroeconomic factors and climate change, particularly in the context of monetary policy. This study builds on (Churchill et al., 2019) by incorporating time-varying parameters and stochastic volatility to assess the environmental effects of monetary policy. Given that the Federal Reserve's primary objectives include price stability and employment, some scholars argue that climate considerations should also be integrated due to their broader economic implications (McKibbin

[1]U.S. Environmental Protection Agency (EPA) estimates that a typical passenger vehicle emits about 4.6 metric tons of carbon dioxide (CO_2) per year.

et al., 2017). Furthermore, Bernanke (Bernanke et al., 1997) emphasized that monetary policy should systematically account for external macroeconomic risks, including climate-related risks. Expanding on this perspective, existing research has explored how macroeconomic variables—such as unemployment, inflation, and climate change—interact within both monetary and climate policy frameworks (Babiker and Eckaus, 2007; Islam et al., 2021; Fankhaeser et al., 2008; Faccia et al., 2021; Boneva et al., 2021). Additionally, (Dafermos et al., 2018) argue that green corporate quantitative easing programs could mitigate financial risks associated with climate change.

These findings underscore the broader role of monetary policy in shaping environmental outcomes, even if its direct impact on emissions is moderate. This study demonstrates that central banks can balance economic growth and environmental sustainability through strategic monetary policy adjustments. Importantly, adopting a more holistic perspective does not require altering the Federal Reserve's mandate but rather recognizing the broader macroeconomic and environmental implications of interest rate changes. While monetary policy alone cannot drive large-scale emissions reductions, its indirect effects reinforce the importance of coordinated macroeconomic and environmental policies. By employing an extended TVP-VAR model with stochastic volatility, this research provides a comprehensive empirical analysis of the dynamic relationship between monetary policy and carbon emissions. These insights contribute to the ongoing discussion on the role of central banks in sustainable economic policy-making, reinforcing the need for an integrated approach to macroeconomic and climate policy.

2. Data and methodology

2.1 The Data

Quarterly time-series data from Q1 1973 to Q4 2024 were collected for carbon emissions, economic growth, the Consumer Price Index (CPI) for all urban consumers (inflation), and the interest rate. The data was sourced from the FRED database and the U.S. Energy Information Administration. This study investigates the impact of monetary policy shocks, particularly interest rate changes, on carbon emissions, with a focus on the channels of economic growth and inflation. For the analysis, carbon emissions are considered in logarithmic form, while the economic growth rate is calculated as the logarithmic difference of real GDP, reflecting the rate of change in economic output over time. Similarly, inflation is represented by the logarithmic difference of the CPI, which captures the rate of change in the price level for urban consumers. The interest rate remains in its original percentage form, reflecting the central bank's monetary policy stance. The analysis focuses on three distinct expansion periods[2], capturing key phases of economic growth and recovery. Using the impulse response function (IRF), these periods were analyzed to assess the impact of a one percent interest rate increase on carbon emissions. Figure 1 presents time series data from 1973 to 2024 for four key variables: carbon emissions (logarithmic scale), economic growth (logarithmic difference of real GDP), inflation (logarithmic difference of the Consumer Price Index), and interest rates. Each graph illustrates fluctuations and trends in these economic indicators over the 52-year period, highlighting cyclical variations, structural shifts, and long-term patterns in the data. Notably, periods of economic crises and policy changes are reflected in the volatility of these series.

[2]NBER (U.S. Business Cycle): Public Use Data Archive, 2022.

Figure 1: Time-Series data for empirical illustration.

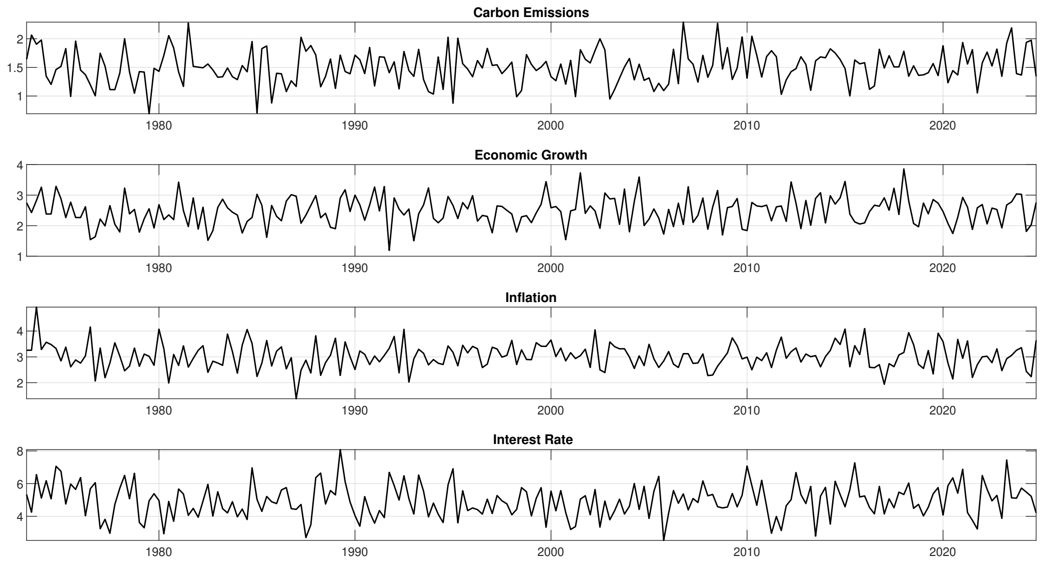


Table 1 presents the descriptive statistics for carbon emissions, real GDP (RGDP), the consumer price index (CPI), and the federal funds rate (FFR). The skewness values for emissions and CPI are close to zero, suggesting that these variables exhibit an approximately symmetric distribution around their means. In contrast, RGDP and FFR show positive skewness, indicating a right-tailed distribution. The kurtosis values for RGDP and FFR are slightly below and above 3, respectively, suggesting that RGDP follows a platykurtic distribution (flatter than normal), while FFR exhibits mild leptokurtic characteristics (more peaked around the mean). The Jarque-Bera test results confirm that the distributions of RGDP, CPI, and FFR significantly deviate from normality, with p-values below 0.05. However, carbon emissions appear to follow a normal distribution, as its p-value exceeds 0.05.

Table 1: Statistical Summary

Statistic	Emissions (MMT)	RGDP (Billion $)	CPI (Index)	FFR (%)
Mean	430.81	13.36	167.24	4.88
Median	429.85	13.25	164.43	5.08
Std. Dev.	44.64	5.12	71.46	3.95
Min	323.95	5.96	43.03	0.06
Max	528.94	23.53	316.54	17.78
Skewness	0.037	0.201	0.073	0.792
Kurtosis	2.311	1.807	2.080	3.471
Jarque-Bera	4.167	13.742	7.520	23.667
p-value	0.124	0.001	0.023	0.000007
Observations	208	208	208	208

Note: MMT = Million Metric Tons, RGDP = Real Gross Domestic Product, CPI = Consumer Price Index, FFR = Federal Funds Rate. p-values correspond to the Jarque-Bera normality test.

2.2 Methodology

The TVP-VAR model with stochastic volatility captures time-varying coefficients and heteroskedasticity in the data, allowing for a more accurate analysis of the dynamic relationship between monetary policy and carbon emissions. A standard structural VAR model with time-invariant parameters assumes that macroeconomic relationships remain stable over time, which may not hold given the evolving nature of economic and environmental policies. Therefore, this study employs a TVP-VAR-SV approach to provide a nuanced understanding of how shifts in monetary policy impact environmental outcomes, allowing for parameter evolution and stochastic volatility.

Monetary policy, through Federal Reserve adjustments to the federal funds rate, significantly impacts economic variables like inflation and economic growth, but its effect on carbon emissions remains underexplored. As central banks integrate climate considerations, this topic becomes increasingly relevant. Higher interest rates can reduce economic activity and emissions by increasing borrowing costs, while lower rates can boost activity and emissions. For the benchmark estimation based on (Primiceri, 2005), the general form of a structural vector autoregression (SVAR) for the TVP-VAR model with p lags is as follows:

$$y_t = B_{0,t} + B_{1,t}y_{t-1} + B_{2,t}y_{t-2} + ... + B_{p,t}y_{t-p} + u_t \tag{1}$$

Here, β_t is the vector of time-varying coefficients, $[B_t, B_{t-1}, ..., B_{t-p}]'$. The reduced form error (u_t) represents unobservable and heteroskedastic structural shocks that follow a Gaussian process with zero mean and covariance matrix Ω_t. The vector y_t ($n \times 1$) includes observed variables such as carbon emissions, economic growth, inflation, and the short-run interest rate as identified by monetary policy. The term $B_{0,t}$ represents the time-varying constant term, while $B_{k,t}$ is the time-varying coefficient matrix ($n \times n$) for $k = 1, 2, ..., p$. For flexibility, $\beta_t = [B_t, B_{t-1}, ..., B_{t-p}]$ follows a first-order random walk process, allowing shifts in coefficients over time. (Nakajima et al., 2011) highlight that these coefficients capture both true movements and spurious variations due to the flexibility of the random walk process.

To study the dynamic relationship between carbon emissions and short-run interest rates, a state-space representation is adopted, where the measurement equation follows Equation (1), and the state equations govern the time evolution of β_t. The reduced-form VAR model is structured as:

$$y_t = X_t^{'\beta_t + A_t^{-1}\Sigma_t\epsilon_t; \quad \epsilon_t \sim N(0,I_n)}(2)$$

where $u_t = A_t^{-1}\Sigma_t\,\epsilon_t$. Here, A_t is a lower triangular matrix with ones on the main diagonal, measuring the contemporaneous relationship of structural shocks based on the recursive identification strategy in (Primiceri, 2005). The matrix Σ_t represents time-varying variances. Unlike (Cogley and Sargent, 2005), which assumes that A_t is time-invariant—implying that an innovation to the i^{th} variable has a constant effect on the j^{th} variable—this paper treats A_t as time-varying while maintaining the Cholesky decomposition approach. The time-varying variance Ω_t is decomposed as follows:

$$\Omega_t = (A_t^{-1})\Sigma_t\Sigma_t^{'(A_t^{-1})'}(3)$$

Assuming that all innovations follow a normal distribution, and the state-space equations follow a non-stationary random walk process, the dynamic parameterization of the model follows (Primiceri, 2005; Koop and Korobilis, 2010; Nakajima et al., 2011; Anand and Paul, 2021):

$$\beta_{t+1} = \beta_t + \nu_t \tag{4}$$

$$\alpha_{t+1} = \alpha_t + \zeta_t \tag{5}$$

$$log\sigma_{t+1} = \log \sigma_t + \eta_t \tag{6}$$

where $\nu_t \sim \mathcal{N}(0, Q)$, independent of ϵ_t; $\zeta_t \sim \mathcal{N}(0, S)$, with S being block diagonal, ensuring that the coefficients of A_t evolve independently in each equation; and $\eta_t \sim \mathcal{N}(0, W)$, where W is diagonal. The vector α_t stacks the lower triangular elements of A_t, and σ_t represents the vector of diagonal elements of Σ_t, capturing time-varying stochastic volatility.

2.2.1 Advantages of the TVP-VAR-SV Model Over the Standard VAR Framework

A standard VAR model assumes time-invariant parameters and constant residual variance, limiting its ability to capture shifts in monetary policy and structural economic changes. The TVP-VAR-SV model is more suitable as it accommodates evolving monetary policy regimes, such as the transition from Volcker-era disinflation to post-2008 unconventional policies. Additionally, the impact of interest rates on emissions varies with changes in industrial structure, energy mix, and climate policies, necessitating a flexible approach. Furthermore, economic and environmental data exhibit time-varying uncertainty due to factors like oil price shocks, financial crises, and inflation volatility, which TVP-VAR-SV effectively accounts for, making it a more robust choice for analyzing the dynamic effects of monetary policy on emissions.
Thus, the TVP-VAR-SV approach is better suited for capturing the dynamic nature of monetary policy's impact on emissions, making it the preferred methodology for this study. The model order follows a logarithmic form of carbon emissions, economic growth, inflation rate, and interest rate, with all variables confirmed to be stationary.

2.3 Model Specification and Identification of Shocks

This methodology captures the dynamic relationship of the system and changing monetary policy rules over time, unlike traditional structural VAR models. This makes TVP-VAR more suitable for identifying monetary policy shocks. Estimation uses maximum likelihood and a Bayesian approach with MCMC (Markov-Chain Monte Carlo) to handle the high-dimensional parameter space and nonlinearity. The model includes 20,000 iterations of the Gibbs sampler, discarding the first 20% as burn-in by (Del Negro and Primiceri, 2015; Nakajima et al., 2011; Primiceri, 2005). Two lags are chosen for estimation followed Primiceri (2005), and priors are calibrated using a time-invariant VAR from 1973:Q1 to 1982:Q4, following methodologies established by (Cogley and Sargent, 2005), and (Primiceri, 2005). To identify the monetary policy shocks, the author follows (Leeper et al., 1996; Bernanke and Mihov, 1998; Primiceri, 2005) and (Christiano et al., 1999), in this paper, by assuming that monetary policy shocks are the monetary policy action that affects inflation, economic growth, and carbon emissions at least one period of lag. Therefore, the interest rate is ordered last in the VAR system. The recursive order of these variables in this model is $\{E_t,\ y_t,\ \pi_t$ and $i_t\}$[3], which follows lower triangular matrix of Cholesky decomposition.

[3] E_t is the natural log of carbon emissions, y_t is the economic growth, π_t is the log difference of cpi for inflation, and i_t is the interest rates

3. Empirical Results

In this paper, the authors consider a U.S. economy with four variables to examine the impulse responses to carbon emissions channeling through economic growth and inflation to a one percent increase in interest rate. The author has chosen three representative expansion periods in the U.S. economy —Q1 2001, Q4 2007, and Q4 2019 —to study the impulse response of carbon emissions to monetary policy shocks. Using TVP-VAR with Stochastic Volatility, the author analyzes carbon emissions, economic growth, inflation, and interest rates by allowing relationships among these variables to change over time. This method captures the dynamic interactions and varying impacts of these variables on each other. Stochastic Volatility accounts for fluctuations in economic conditions, providing a robust framework to understand how economic policies and external shocks influence carbon emissions and overall economic stability.
To assess how monetary policy impacts emissions over time, the author examine three periods: 1985Q1–2010Q4 (pre- & post-2001 shock), 1995Q1–2016Q4 (pre- & post-2007 shock), and 2009Q1–2024Q4 (pre- & post-2019 shock). These periods capture major economic cycles, including the dot-com bubble, the Global Financial Crisis, and the COVID-19 pandemic. Given the limitations of standard VAR models in assuming constant relationships, the TVP-VAR-SV approach better captures the evolving macroeconomic and policy dynamics affecting emissions.
The posterior mean of the standard deviation of residuals for carbon emissions, economic growth, inflation, and interest rates is presented in Table 2 and Figure 2. These results highlight the variability in economic relationships over time, reinforcing the need for stochastic volatility modeling. Carbon emissions and inflation exhibit moderate fluctuations, whereas economic growth and interest rates display heightened volatility, particularly during economic shocks.

Table 2: Descriptive Statistics for the Standard Deviations of Residuals

Equation	**Mean**	**Std Dev**	**Min**	**Max**
Equation 1	0.031904	0.017879	0.019095	0.182914
Equation 2	0.002981	0.001882	0.001686	0.015473
Equation 3	0.001653	0.000310	0.001306	0.002719
Equation 4	0.313448	0.215040	0.054501	1.314710

The findings suggest that monetary and economic policies have dynamic and time-varying effects on these key indicators. These results underscore the necessity of adaptive macroeconomic policies that account for evolving volatility in emissions, economic growth, inflation, and interest rates to ensure effective policy interventions.

Figure 2: Posterior estimates for stochastic volatility of structural shocks.

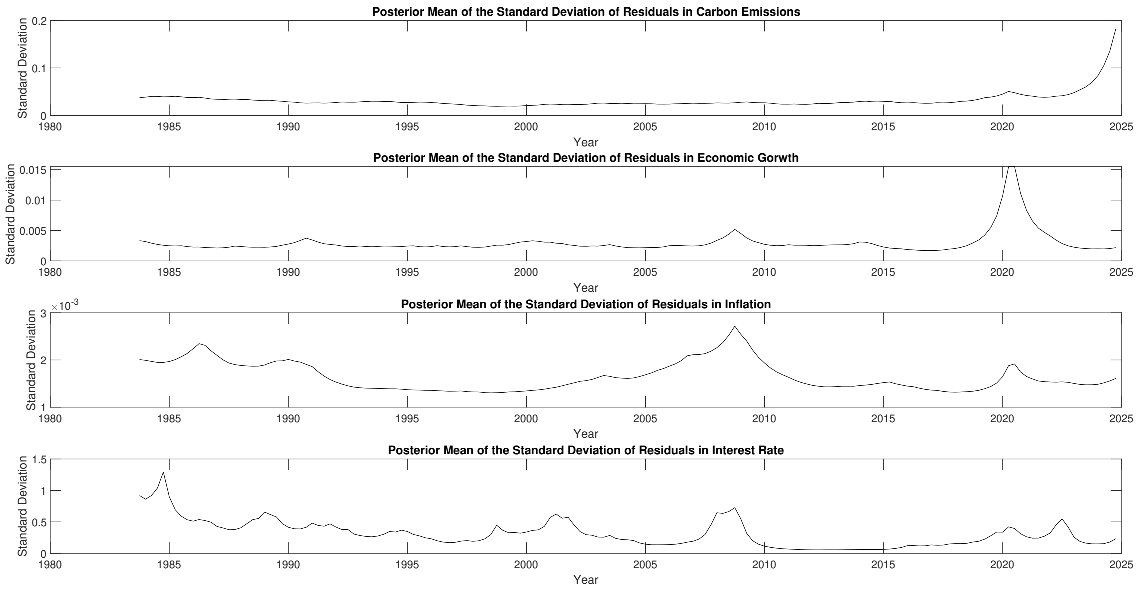


Figure 2 presents the posterior mean of the standard deviations of residuals, highlighting the varying degrees of volatility across emissions, economic growth, inflation, and interest rates. Carbon emissions exhibit moderate and relatively stable residual fluctuations, while economic growth shows periods of heightened volatility, particularly during economic shocks. Inflation displays moderate but persistent variability, whereas interest rates exhibit the highest residual volatility, reflecting the dynamic nature of monetary policy adjustments. These findings underscore the model's ability to capture evolving economic relationships with greater precision in relatively stable variables and increased uncertainty in more responsive indicators such as interest rates. Recognizing these patterns enhances the robustness of the model and informs policy decisions by accounting for time-varying economic fluctuations.

Table 3 presents the estimated time-varying coefficients, illustrating the dynamic interactions between emissions, economic growth, inflation, and interest rates. The significant intercept establishes a strong baseline effect on emissions. Emissions exhibit persistence, with a positive first lag ($\beta_2 = 0.0496$) suggesting inertia in emissions levels, while the smaller second lag ($\beta_3 = 0.0147$) indicates a gradual adjustment over time. The impact of economic growth is pronounced, with the first lag ($\beta_4 = 5.6710$) reflecting a strong short-term influence on emissions, which moderates in the second lag ($\beta_5 = 0.3268$). Inflation follows a similar dynamic, where the first lag ($\beta_6 = 0.5935$) suggests inflationary pressures initially contribute to emissions, supporting the argument that rising price levels stimulate production and energy use, as propounded by (Sims, 1992). However, the second lag ($\beta_7 = -2.1098$) indicates a corrective effect as economic adjustments take place.

Table 3: Summary of TVP-VAR Model Coefficient Estimates with Stochastic Volatility

Parameter	Variable	Mean	Std Dev	2.5% - 97.5% CI
β_1	Intercept	1.2625	0.1196	[1.0692, 1.4798]
β_2	Emissions$_{t-1}$	0.0496	0.0139	[0.0286, 0.0799]
β_3	Emissions$_{t-2}$	0.0147	0.0100	[0.0006, 0.0334]
β_4	Economic Growth$_{t-1}$	5.6710	3.5997	[0.6724, 12.3183]
β_5	Economic Growth$_{t-2}$	0.3268	0.0151	[0.2961, 0.3489]
β_6	Inflation$_{t-1}$	0.5935	0.1294	[0.3880, 0.8516]
β_7	Inflation$_{t-2}$	-2.1098	0.3365	[-2.5746, -1.6277]
β_8	Interest Rate$_{t-1}$	0.0069	0.0007	[0.0061, 0.0082]
β_9	Interest Rate$_{t-2}$	-0.0006	0.0028	[-0.0059, 0.0027]

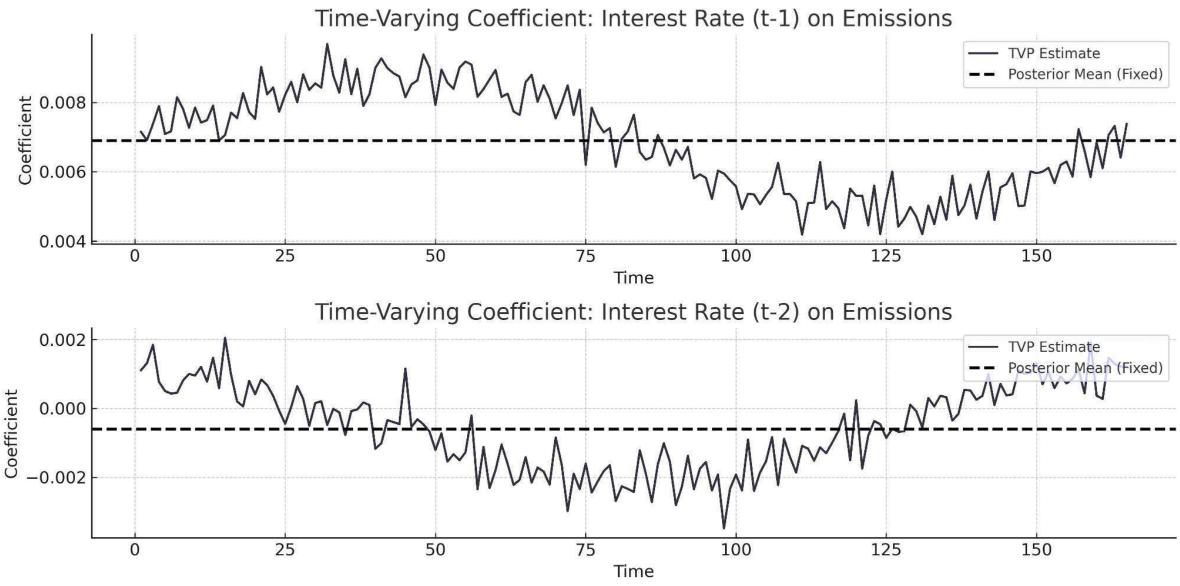
The response to monetary policy shocks is time-varying—while the first lag of interest rates ($\beta_8 = 0.0069$) suggests a short-term increase in emissions, the second lag ($\beta_9 = -0.0006$) aligns with theoretical expectations of a contractionary effect, reinforcing the anticipated dampening influence of interest rate hikes. These findings underscore the necessity of TVP-VAR models to capture evolving macroeconomic influences on emissions. Full coefficient estimates, along with confidence intervals, are reported in Table 3.

Figure 3 reflects the estimated time-varying coefficients for the interest rate (t-1) and interest rate (t-2) on emissions, as presented in Table 3. The solid grey line represents the dynamic evolution of these coefficients over time, showing how the relationships change throughout the study period. The dashed black line corresponds to the posterior mean estimates for both coefficients, which align with the mean estimates reported in Table 3: β_8 = 0.0069 for the interest rate (t-1) and β_9 = -0.0006 for the interest rate (t-2).

The fluctuations observed in the time-varying estimates (solid grey line) remain within the 95% credible intervals presented in Table 3, reinforcing the robustness of the results. These variations highlight the dynamic impact of monetary policy on carbon emissions over time, reflecting how the relationship evolves in response to changing economic conditions. This alignment between the time-varying coefficients and the posterior means from Table 3 underscores the necessity of using a TVP-VAR model with stochastic volatility, which allows for capturing the dynamic nature of the monetary policy effects on emissions across different periods.

Figure 4 presents the posterior mean (solid line) and the 16th and 84th quantile credible intervals (dotted lines) of impulse responses for carbon emissions (Emissions), economic growth (EG), inflation, and interest rate over a 36-quarter horizon following a one percentage point increase in interest rates. The analysis considers three expansion periods: Q1 2001, Q4 2007, and Q4 2019. Carbon emissions initially exhibit a modest increase, reflecting short-term production adjustments, before declining persistently.The estimated cumulative reduction reaches 27.73 million metric tons (MMT) after 12 quarters in 2001:Q1, 25.55 MMT in 2007:Q4, and 18.18 MMT in 2019:Q4.

Figure 3: Estimated Time-Varying Coefficients for the Impact of Interest Rate on Emissions.



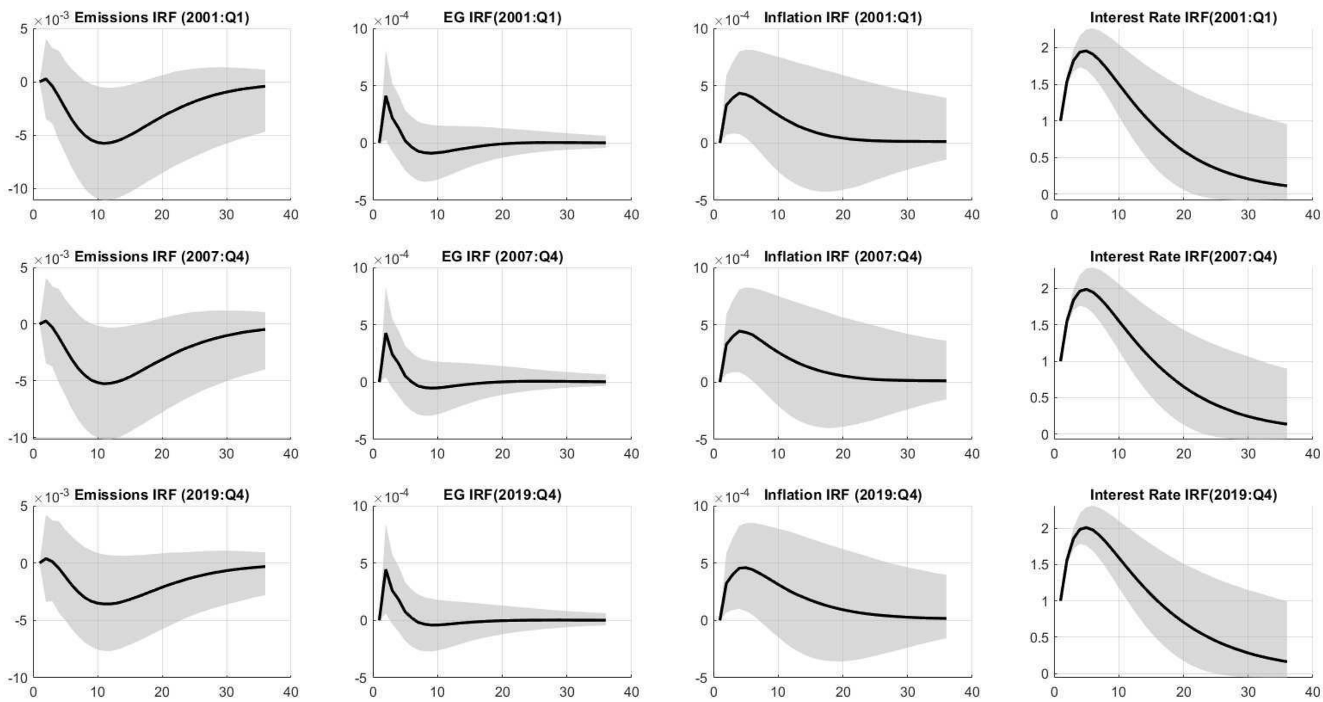
This weakening effect suggests that the influence of monetary policy on emissions has declined over time due to energy efficiency improvements and structural economic changes, aligning with (Frankel et al., 2008; Kilian and Zhou, 2022).

Economic growth initially rises but contracts as higher borrowing costs dampen investment and consumption, consistent with the aggregate demand channel (Blanchard, 2005; Primiceri, 2005; Koop and Korobilis, 2010). Inflation exhibits a temporary increase, consistent with the price puzzle (Sims, 1992). Robustness tests replacing inflation with commodity prices (oil, gold, and silver) further validate these findings.

The results highlight that while contractionary monetary policy reduces emissions, its effectiveness has weakened due to evolving economic structures and financialization, supporting the empirical findings of (Chishti et al., 2021). These findings reinforce the importance of using time-varying models to capture the dynamic interactions between monetary policy and environmental outcomes.

Figure 5 presents the impulse response functions of carbon emissions to a one percentage point interest rate shock, estimated using a standard vector autoregression (VAR) model. Panels (a)–(d) display the responses for the full sample period (1973Q2–2024Q4) and three sub-periods: 1985Q1–2010Q4, 1995Q1–2016Q4, and 2009Q1–2024Q4. Each panel focuses exclusively on the emissions response, with vertical axes rescaled to enhance interpretability. The full-sample response reflects the average effect of monetary policy over time, while the sub-period estimates reveal structural shifts in the transmission mechanism across different economic environments. The responses vary substantially across periods, highlighting the instability of the monetary policy-emissions relationship. In some periods, emissions increase in response to higher interest rates, while in others they decline. This irregular pattern suggests that the link between monetary policy and environmental outcomes is not time-invariant. These inconsistencies point to a key limitation of the standard VAR framework—its assumption of fixed relationships between variables—which may be inadequate in the context of evolving macroeconomic and structural conditions. Given that the effectiveness of monetary policy depends on factors such as financial market development, industrial structure, and technological change, a more flexible empirical approach may be required to fully capture the dynamics at play.

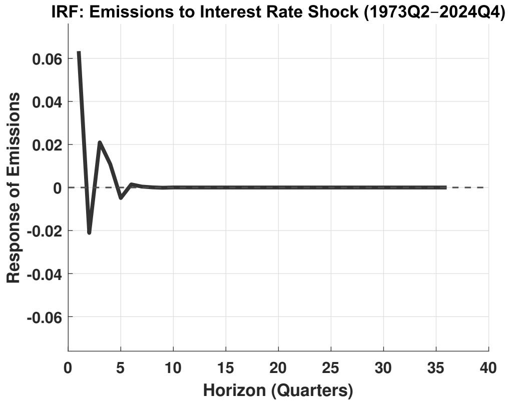
Figure 4: Impulse responses of emissions, economic growth, and inflation to monetary policy shock at different expansion periods.



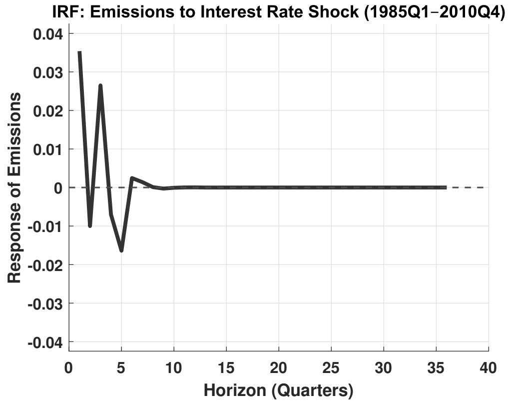
To address these limitations and better capture the evolving nature of monetary policy transmission, the TVP-VAR-SV model provides a more robust framework by allowing the relationships between variables to evolve dynamically. Unlike the Standard VAR, which imposes constant parameter restrictions, the TVP-VAR-SV results reveal a larger and more persistent decline in emissions, with reductions of 27.73 MMT in 2001:Q1, 25.55 MMT in 2007:Q4, and 18.18 MMT in 2019:Q4. This highlights how the effectiveness of monetary policy in reducing emissions has weakened over time, likely due to rising energy efficiency, sectoral shifts, and financialization (Frankel et al., 2008; Kilian and Zhou, 2022). Additionally, the TVP-VAR-SV model better reflects evolving economic conditions, showing a more pronounced contraction in economic growth and a gradual inflation response compared to the Standard VAR. These findings reinforce the necessity of employing time-varying models to assess the changing impact of monetary policy on emissions and broader macroeconomic dynamics more accurately.

A robustness test replaced economic growth and inflation rates with gross private domestic investment and WTI spot crude oil prices, following the economic literature (Mojon et al., 2002; Cloyne et al., 2018; Givens and Reed, 2018). The results confirm that contractionary monetary policy significantly reduces investment, carbon emissions, and oil prices, reinforcing the transmission of monetary tightening through financial and commodity markets. The decline in oil prices, driven by reduced drilling and exploration, further supports the finding that higher interest rates dampen economic activity and emissions, consistent with the broader macroeconomic adjustment mechanism.

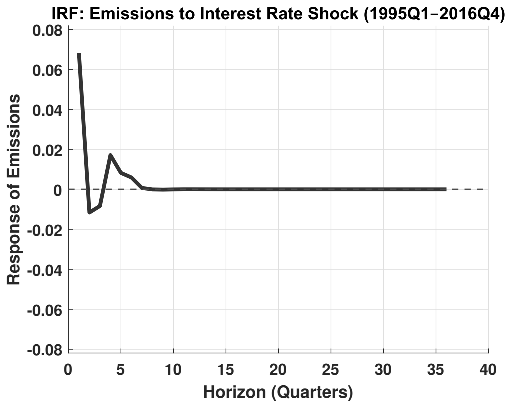
Figure 5: Impulse responses of carbon emissions to monetary policy shocks across different periods.



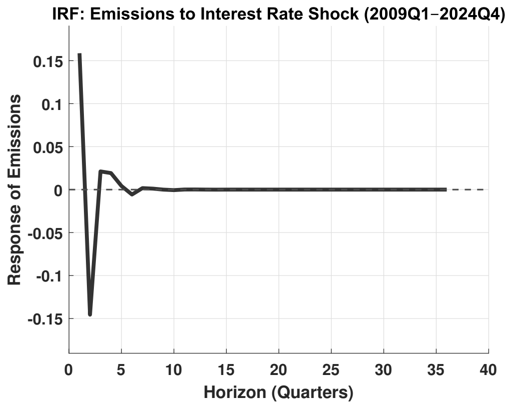
(a) All Periods



(b) Period 1



(c) Period 2



(d) Period 3

4. Conclusions

This study examines the impact of U.S. monetary policy on carbon emissions using a Time-Varying Parameter Vector Autoregression (TVP-VAR) model with stochastic volatility, analyzing quarterly data from 1973Q1 to 2024Q4. Unlike traditional models, the TVP-VAR-SV framework captures the evolving nature of macroeconomic relationships, providing a more comprehensive assessment of monetary policy's environmental effects. The findings indicate that a one percentage point increase in the interest rate leads to a reduction in emissions of 27.73 million metric tons (MMT) in 2001:Q1, 25.55 MMT in 2007:Q4, and 18.18 MMT in 2019:Q4, demonstrating a declining effect of monetary policy on emissions over time. This weakening response is likely due to both structural shifts—such as increased energy efficiency and financialization—and one-time shocks, including economic crises and policy interventions, suggesting that the effectiveness of monetary policy in reducing emissions has diminished in recent decades.

Additionally, the impulse response functions from the standard VAR model show notable variation in the effect of monetary policy on carbon emissions across periods. While emissions increase in response to interest rate shocks in earlier periods, they decline in later ones, reflecting structural changes in the economy. These shifts underscore a key limitation of the standard VAR—its assumption of time-invariant relationships. In contrast, the TVP-VAR-SV model captures evolving transmission dynamics and reveals a more consistent emissions reduction following monetary tightening. This highlights the advantage of time-varying frameworks in assessing the environmental impacts of macroeconomic policy.

The study's findings have significant policy implications. While monetary policy has historically contributed to emissions reductions through its impact on economic activity, its role in climate policy is weakening. This underscores the need for complementary fiscal and regulatory measures to achieve environmental goals. Furthermore, robustness tests, including alternative measures of economic variables, confirm the stability of these findings, reinforcing the importance of adaptive and responsive policy frameworks. By highlighting the interconnectedness of monetary policy and environmental outcomes, this research contributes to the broader debate on sustainable economic policymaking. Future research should further explore how financial markets, industrial transitions, and global monetary coordination shape the evolving relationship between monetary policy and carbon emissions.

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