# Examining the Impact of Monetary Policy in Turkey: TVP-VAR with Stochastic Volatility

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Received: 25 March 2023; 21 January 2025.

**Abstract**

This study aimed to examine the time-varying effects of monetary policy on macroeconomic variables, addressing the price puzzle problem in Turkey from 1994 and 2020 by using a time-varying parameter vector autoregression with a stochastic volatility model. The spread between long-term and short-term interest rates served as a measure of monetary policy. The empirical evidence indicated that positive innovations in the spread decrease inflation, economic activity, total credit, and the exchange rate. Moreover, it was determined that the responses to monetary policy shocks have changed over time. The responses to positive innovations in the spread increased in absolute value after 2017, suggesting that the effects of monetary policies implemented after this period on the economy have intensified. These findings underscore the need to employ a time-varying model alongside dynamic monetary policy measures to ascertain the changing effects of policy interventions. Therefore, Turkish policymakers should consider the increasing sensitivity of the economy to monetary policy actions when designing future interventions, particularly for managing inflation and stabilizing economic activity.

**Keywords**: Monetary policy; Time-varying estimation; Vector autoregression

**JEL**: C11; C32; E52

## 1. Introduction

Examining the effects of monetary policy has long been a fundamental topic of economics research, with identifying suitable measures of monetary policy tools remaining a significant endeavor. This is because commonly used metrics such as monetary aggregates (M1 or M2) or interest rates often prove insufficient for capturing the complex dynamics of monetary policy (Benjamin Friedman and Kenneth N. Kuttner 1992; Hakan Berument et al. 2014). Vector autoregression (VAR) models, which are widely used to examine monetary policy effects, often yield the "price puzzle," with empirical findings contradicting theoretical expectations (Ben S. Bernanke and Alan S. Blinder, 1992; Christopher A. Sims, 1992; Lawrence J. Christiano et al. 1996). This puzzle raises doubts about the accuracy of VAR models used to detect monetary policy shocks (Danielle Rusnak et al. 2012; Paolo Giordani, 2004).

To address the price puzzle, interest rate spread has generally been employed in the existing literature. Interest rate spread can be defined as the difference between short- and long-term rates, which provides vital information about the expectations of future actions (Robert D. Laurent, 1988; James H. Stock and Mark W. Watson, 1989; Ben S. Bernanke, 1990; Bennet T. McCallum, 2007; Dieter Nautz and Christian J. Offermanns, 2008; Berument et al. 2014; Philip Arestis et al. 2021; Arturo Estrella 2005). In the present study, the interest rate spread was used as a monetary policy measure, as suggested by Berument et al. (2014), and the time-varying effects of monetary policy on macroeconomic variables were examined, accounting for the price puzzle problem in Turkey between 1994 and 2020.

The Turkish economy underwent significant structural changes during this period, marked by political instability, economic crises, and policy shifts, making traditional VAR models unsuitable for examining monetary policy effects. Therefore, this study utilized the time-varying parameter VAR model with stochastic volatility (TVP-VAR-SV) proposed by Giorgio E. Primiceri (2005), which captures nonlinear, time-varying relationships between economic variables. The results show that positive shocks to the interest rate spread reduce inflation, economic activity, total credit, and the exchange rate, emphasizing the need for flexible policy frameworks to respond to changing economic conditions. This study makes two main contributions: (1) it is the first study in Turkey to investigate monetary policy effects using interest rate spread in TVP models, and (2) it examined changes in monetary policy since 2017, when Turkey's economic fragility began to increase.

The following section provides a review of the literature. Following it, Section 3 explains the econometric model, Section 4 presents the data and model specifications used in the study, Section 5 reports the empirical evidence, and, finally, Section 6 discusses the results.

## 2. The Turkish Economy and a Literature Review

This section is structured into two distinct subsections. The first provides a historical and macroeconomic overview of the Turkish economy from 1994 to 2020, detailing the crucial role of monetary policy during periods of economic turmoil. The second subsection carried out a comprehensive literature review, focusing on how monetary policy impacts macroeconomic variables, particularly through the lens of TVP-VAR models, which highlight the unique challenges and insights specific to the Turkish context.

### 2.1. The Turkish Economy: A Historical and Macroeconomic Overview

This section explores the significant structural transformations and accompanying political and economic instabilities experienced by the Turkish economy between 1994 and 2020, examining how monetary policy became a crucial management tool during these challenging periods to achieve key macroeconomic objectives while addressing issues such as chronic inflation, financial instability, and external dependencies. The subsequent portion of this section conducts a thorough literature review, focusing on studies analyzing the Turkish economy. The insights gleaned from TVP-VAR models are emphasized, underscoring the unique challenges and characteristics encountered in this context. This dual approach provides a comprehensive understanding of the underlying mechanisms influencing major economic events and policy shifts in Turkey, thereby enhancing our perspective on the dynamic interplay between policy actions and macroeconomic outcomes.

Between 1990 and 2020, the Turkish economy experienced significant growth alongside numerous financial, economic, and political crises. During this period, monetary policy became an essential tool for achieving key macroeconomic goals such as economic growth, increased employment, and price stability. However, challenges such as chronic high inflation, a fragile financial structure, and external dependence posed significant threats to economic management (Cengiz Aktaş, 2000). The 1990s were characterized by political instability, high inflation, and frequent devaluations, with the 1994 crisis emerging due to growing public deficits and misguided external borrowing policies (Hasan Ersel et al. 2005). Although the April 5 stabilization measures aimed to restore economic balance, the 1997 Asian and 1998 Russian crises disrupted these efforts. The 1999 Marmara earthquake further compounded economic difficulties, delaying the recovery process. The 2001 crisis, culminating in the collapse of the stand-by agreement with the International Monetary Fund (IMF), paved the way for implementing the “Transition to a Strong Economy” program (Yılmaz Akyüz and Korkut Boratav, 2003).

From 2002 onward, the Turkish economy experienced periods of structural reform and relative stability. Adopting a floating exchange rate regime and the inflation targeting strategy were significant steps toward macroeconomic stability

(Central Bank of the Republic of Turkey [CBRT], 2006). Moreover, implicit inflation targeting was applied between 2002 and 2005, followed by an explicit inflation targeting regime from 2006 onward (Hakan Kara and Musa Orak, 2008). During this period, the Central Bank played a crucial role in maintaining price stability and strengthening transparency and accountability.

The 2008 global financial crisis adversely affected the Turkish economy, although a swift recovery followed. In the aftermath, unconventional monetary policy tools were introduced to ensure financial stability. Instruments such as the policy rate, liquidity management, interest rate corridor, reserve requirements, and the reserve option mechanism were employed to mitigate economic fluctuations. Nevertheless, structural issues and vulnerability to global developments persisted in the Turkish economy, with challenges such as high inflation, external debt burden, and political instability continuing to impede economic performance. In the 2010s in particular, growing political uncertainties weakened the effectiveness of economic policies and adversely impacted growth performance (Fatih Özatay, 2018). The 2018 currency crisis exposed these vulnerabilities once again (Özgür Orhangazi, 2020).

The period between 1994 and 2020 underscores the dynamic nature of the Turkish economy and the challenges it faced, emphasizing the critical role of monetary policy in maintaining and sustaining economic stability. The experiences of this period emphasize the importance of structural reforms, the necessity of maintaining macroeconomic stability, and the need to build a resilient economy capable of adapting to global developments (IMF, 2017).

## 2.2. Review of Literature on Monetary Policy Transmission

While the preceding section outlined the major economic events and policy shifts in Turkey, a deeper understanding of the underlying mechanisms requires a closer inspection of the academic research on monetary policy transmission.

Jun Nagayasu (2007) examined the impact of monetary policy on the yen's exchange rate and its effect on economic growth in Japan. Interestingly, while monetary expansion did lead to a depreciation of the yen, this did not translate into economic growth, raising questions about the effectiveness of using the exchange rate as a tool for stimulating the economy. Building on this examination of the exchange rate's role in monetary policy transmission, researchers have also investigated whether the very transmission mechanism evolves over time. Koop et al. (2009) explored this question, finding that both the mechanism and the external environment are dynamic and interrelated, thus highlighting the complexity of analyzing monetary policy effects. This dynamic nature is further underscored by Jouchi Nakajima et al. (2011), who focused on the Japanese economy and found that the effects of monetary policy shocks change over time. Similarly, Michal Franta et al. (2014) examined the monetary policy transmission mechanism in the Czech Republic, observing that prices have become more sensitive to monetary policy shocks, which suggests that Central Bank actions may have a more immediate and pronounced impact on inflation.

To capture these evolving dynamics, several researchers have turned to TVP-VAR models. Olga Arratibel and Henrike Michaelis (2014) employed such a model to analyze the Polish economy, finding that the output gap's sensitivity to interest rate shocks changed over time. This highlights the usefulness of TVP-VAR models in capturing the evolving dynamics of monetary policy transmission. To further demonstrate the versatility of this approach, Philipp T. Dybowski et al. (2018) employed a TVP-VAR model to study the Bank of Canada's monetary policy, determining that the factors influencing the policy rate, particularly the role of the exchange rate, changed over time. This suggests that central banks may adjust their policy reaction functions in response to changing economic conditions.

Beyond the core components of the transmission mechanism, researchers have also explored the influence of financial conditions on monetary policy effectiveness. Abdurrahman Çatik and Coşkun Akdeniz (2019) examined this relationship in the context of Turkey, finding that financial constraints significantly impact how monetary policy affects the economy, especially during financial crises. This underscores the importance of considering financial market conditions when analyzing monetary policy. In a related study, Coşkun Akdeniz and Nazif Çatık (2019) also studied the evolution of Turkey's monetary transmission mechanism, revealing that adopting inflation targeting affected the functioning of transmission channels. However, their results indicated a potential identification error in their model.

More recently, scholars have continued to refine and apply these analytical tools to a wider range of contexts. For instance, in several studies, TVP-VAR models have been used to investigate various aspects of monetary policy, including the impact of economic policy uncertainty (Song et al. 2021), the unique characteristics of China's monetary policy transmission (Kim, 2021; Yang and Zhang, 2021; Deng and Wu, 2023; Sun and Liue, 2023), the causes of the Great Moderation (Prüser, 2021), and the evolution of monetary policy in Peru (Portilla et al. 2022). In other research, the interaction between monetary and fiscal policies (Hakimabadi et al. 2022; Oyeleke et al. 2022), the connectedness of economic policy uncertainty indices (Nyakurukwa and Seetharam, 2023), and the impact of monetary policy uncertainty across major economic events (Kamara and Koirala, 2023) have been explored.

This literature review begins by examining key international studies contributing to our knowledge of how monetary policy actions affect macroeconomic variables. The focus then narrows to explore studies that specifically analyze the Turkish economy, highlighting the insights gained from TVP-VAR models and the unique challenges and characteristics of this context. A pertinent example of this is the study by Coşkun Akdeniz and Nazif Çatık (2019), which investigated the evolution of

Turkey's monetary transmission mechanism with a TVP-VAR model, particularly the impact of inflation targeting on transmission channels. However, Coşkun Akdeniz and Nazif Çatık's analysis may have been compromised by an identification error associated with the price puzzle, a phenomenon in which increases in interest rates paradoxically coincide with increases in inflation, potentially distorting the true effects of monetary policy. To address this gap, we utilized the spread between long- and short-term interest rates as a more stable and precise measure for assessing monetary policy impacts. This methodological refinement allowed us to circumvent the identification problems encountered in previous studies, providing clearer and more reliable insights into how monetary policy influences macroeconomic variables in Turkey.

## 3. Methodology

Time-varying coefficient models have been extensively explored in the literature (Fabio Canova, 1993; Christopher A. Sims, 1993; James H. Stock and Mark W. Watson, 1998; Timothy Cogley and Thomas J. Sargent, 2001; Primiceri, 2005). Moreover, in the literature, Primiceri's (2005) TVP-VAR-SV model is widely used, especially when examining macroeconomic issues. The TVP-VAR model enables us to establish the economy's time-varying structure flexibly and robustly. The VAR specification assumes all parameters follow a first-order random walk process, permitting temporary and permanent parameter shifts. Further, the TVP-VAR model relies on SV since a model with time-varying coefficients but constant volatility raises questions about potential bias in the calculated coefficients due to ignored disturbance volatility. TVP-VAR assumes SV to avoid misspecification (Nakajima, 2011). The concept of SV was originally proposed by Fischer Black (1976), followed by numerous studies in financial econometrics (see Eric Ghysels et al. 1996; Neil Shephard, 2005). The TVP-VAR-SV model is estimated using Markov chain Monte Carlo (MCMC) methods in Bayesian inference. However, it is difficult to estimate the coefficients due to SV as it makes it challenging to obtain the likelihood function. Primiceri (2005) was the first author to examine monetary policy with the TVP-VAR-SV model. The monetary policy and private sector behavior were analyzed with structural VAR models that change over time, and it was determined that both systematic and unsystematic monetary policy have changed. Moreover, despite considerable fluctuations, the interest rate's systematic responses to impact and unemployment tended toward more aggressive behavior.

The present study employed a TVP-VAR-SV model to reveal the time-varying effects of monetary policy in Turkey. It is an extension of the basic structural VAR model.

The basic VAR model can be presented as

$$Ay_t = F_1 y_{t-1} + \cdots + F_s y_{t-s} + u_t, t = s+1, \ldots, n, \quad (1)$$

where $y_t$ is a $k \times 1$ vector of observed variables, $A, F_1, \ldots, F_s$ are $k \times k$ coefficient matrices, and $u_t$ is a $k \times 1$ structural shock following a multivariate $N(0, \Sigma\Sigma')$.

$$\Sigma_u = \begin{bmatrix} \sigma_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_1 \end{bmatrix} \text{ and } A = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ a_{k1} & \cdots & a_{k,k-1} & 1 \end{bmatrix}.$$

The reduced form of this model can be written as follows:

$$y_t = B_1 y_{t-1} + \cdots + B_s y_{t-s} + A^{-1} \Sigma\varepsilon_t, \varepsilon_t \sim N(0, I_k), \quad (2)$$

Here,

$$B_i = A^{-1} F_i, i = 1, \ldots, s \quad (3)$$

This form can be expressed as follows:

$$y_t = X_t \beta + A^{-1} \Sigma\varepsilon_t, \varepsilon_t \sim N(0, I_k), \quad (4)$$

Here, $X_t = I_s \otimes (y'_{t-1}, \ldots, y'_{t-s})$.

The TVP-VAR model can be constructed by allowing coefficients and the variance–covariance matrix to change over time. The TVP-VAR-SV model is as follows:

$$y_t = X_t \beta_t + A_t^{-1} \Sigma_t \varepsilon_t, t = s+1, \ldots, n, \quad (5)$$

Here, the coefficient $\beta_t$ and parameters $A_t$ and $\Sigma_t$ are all time-varying.

There are two assumptions for ease of calculation. First, it is assumed that $A_t$ is a lower triangular matrix. Second, the parameters in (5) follow a random walk process. Since the TVP-VAR model has several parameters, it is better to reduce the number of parameters by assuming a random walk process for the innovation of parameters. Most studies that use a TVP-VAR model assume a random walk process for parameters (Nakajima, 2011). The model is as follows:

$$\beta_t = \beta_{t-1} + u_{\beta t} \quad (6)$$

$$a_t = a_{t-1} + u_{at} \quad (7)$$

$$h_t = h_{t-1} + u_{ht} \quad (8)$$

Here, $a_t = (a_{21}, a_{31}, \dots, a_{k,k-1})$ is a stacked vector of the lower-triangular elements in $A_t$ and $h_t = (h_{1t}, \dots, h_{kt})$ with $h_t = log\sigma_{jt}^2$ for $j = 1, \dots, k,\ t = s+1, \dots, n$. Further, $\beta_{s+1} \sim N(\mu_{\beta_0}, \Sigma_{\beta_0})$, $a_{s+1} \sim N(\mu_{a_0}, \Sigma_{a_0})$, and $h_{s+1} \sim N(\mu_{h_0}, \Sigma_{h_0})$ with

$$Var\left(\begin{bmatrix} \varepsilon_t \\ u_{\beta t} \\ u_{at} \\ u_{ht} \end{bmatrix}\right) = \begin{bmatrix} I_n & 0 & 0 & 0 \\ 0 & \Sigma_{\beta_0} & 0 & 0 \\ 0 & 0 & \Sigma_{a_0} & 0 \\ 0 & 0 & 0 & \Sigma_{h_0} \end{bmatrix}.$$

The estimation process for TVP-VAR-SV models differs from that for classical methods. In the case of constant volatility, Equations (5), (6), and (7) can be expressed as a Gaussian state-space model, allowing the standard Kalman filter to be used for estimation. Since SV is used in the model, Bayesian methods are employed for estimation. As equation (8) forms a nonlinear state-space model, it can be written in state-space form, and MCMC methods are used for estimation.

Given the data $y$, a sample from the posterior distribution $\pi(\beta, a, h, w|y)$ is generated using the MCMC method where $w = (\Sigma_\beta, \Sigma_a, \Sigma_h)$. The MCMC algorithm involves the following steps:

| | |
|---|---|
| 1 | Initialize $\beta, a, h,$ and $w$ |
| 2 | Sample $\beta$ from $p(\beta\|a, h, \Sigma_\beta, y)$ |
| 3 | Sample $\Sigma_\beta$ from $p(\Sigma_\beta\|\beta)$ |
| 4 | Sample $a$ from $p(a\|\beta, h, \Sigma_a, y)$ |
| 5 | Sample $\Sigma_a$ from $p(\Sigma_a\|a)$ |
| 6 | Sample $h$ from $p(h\|\beta, a, \Sigma_h, y)$ |
| 7 | Sample $\Sigma_h$ from $p(\Sigma_h\|h)$ |
| 8 | Return to (2) |

## 4. Data and Model Specifications

### 4.1. Data

The time-varying effects of monetary policy on macroeconomic variables in Turkey between February 1994 and September 2020 were examined using monthly data for the industrial production index, consumer price index, total domestic credit, exchange rate, and interest rate spread. The data were obtained from the CBRT and seasonally adjusted using the TRAMO/SEATS method[1]. The exchange rate used is based on the official currency basket followed by the CBRT for its operations, which consists of 0.5 USD and 0.5 euros. For the years before the introduction of the euro in 1999, the official conversion rate between the euro and the Deutsche Mark (DM) was used. Thus, the basket for the period before 1999 was calculated as 0.5 USD + 0.974027 DM (Berument et al. 2014). The relationships between the variables were analyzed within the framework of key macroeconomic theories such as exchange rate pass-through, purchasing power parity, uncovered interest rate parity, the Phillips curve, and the Taylor rule. These theories provide a foundation for understanding the effects of monetary policy decisions on inflation, exchange rates, economic activity, and credit volume.

Furthermore, the interbank overnight interest rate and the Treasury auction rate were also obtained from the CBRT and the Presidency of Strategy and Budget. The definition of interest rate spread is the same as that used by Berument et al. (2014), obtained by taking the difference between the treasury auction interest rate and the overnight interest rate. In several studies, the spread concept has been defined in association with different macroeconomic variables, and the difference between short- and long-term interest rates has been addressed (Robert D. Laurent, 1988; Stock and Watson, 1989; Bernanke, 1990; Berument, 2007; Bennet T. McCallum, 2007; Hakan Berument, 2007; Dieter Nautz and Christian J. Offermanns, 2008; Hakan Berument et al. 2014). A higher overnight rate relative to the auction rate (with all other factors unchanged) indicates a tighter monetary policy. Because the Central Bank provides a lower level of liquidity to the market than what the market accepts, it is usually expected that output and inflation will decline in subsequent periods.

Percentage changes in all variables, except interest rate spread, compared to one period ago were taken. After transformation, the variables taken, i.e., spread (Δ), total

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[1] The TRAMO/SEATS method utilizes signal extraction techniques based on an ARIMA-type model that describes the behavior of the series. Building on the work by researchers such as Peter J. Burman (1980) and Stevan C. Hillmer and George C. Tiao (1982), TRAMO/SEATS employs advanced filtering techniques to decompose the series into its key components: seasonal, trend-cycle, and irregular. Moreover, it offers the ability to pre-adjust the series to remove deterministic effects such as trading day variations, moving holidays, and outliers. By incorporating these features, TRAMO/SEATS ensures accuracy and reliability in the seasonal adjustment process.

credit (%), nominal exchange rate (%), industrial production index (%), and consumer price index (%) were abbreviated as $s_t$, $cre_t$, $exc_t$, $ip_t$, and $inf_t$, respectively. Table 1 presents the mean, standard deviation, and Jarque–Bera statistics of the variables, while Table 2 presents the stationarity test results of the variables.

Table 1. Descriptive statistics of the variables

| Variables | Mean | Std. Dev. | Skewness | Kurtosis | Jarque–Bera |
|---|---|---|---|---|---|
| $cre_t$ | 2.854 | 3.514 | 1.912 | 12.959 | 1517.456* |
| $exc_t$ | 2.089 | 5.295 | 4.213 | 38.535 | 17782.530* |
| $s_t$ | -10.373 | 35.239 | 1.695 | 31.535 | 11009.940* |
| $ip_t$ | 0.436 | 3.543 | -1.079 | 23.719 | 5785.694* |
| $inf_t$ | 2.047 | 2.463 | 2.781 | 19.819 | 4184.265* |

*indicates the null hypothesis that the variables are normally distributed is rejected at the 5% significance level

The method commonly used to test for the presence of unit roots in the series is the augmented Dickey–Fuller (ADF) test suggested by Dickey and Fuller (1981). However, Perron (1989) argued that the ADF test is biased toward the non-rejection of the unit root null hypothesis in the presence of a broken trend. Therefore, Eric Zivot and Donald W. K. Andrews (1992), Pierre Perron (1997), and Timothy J. Vogelsang and Pierre Perron (1998) recommended unit root tests that allow structural breaks to be determined endogenously from the data. The procedure developed by Vogelsang and Perron (1998) was also used to test the null of the unit root against the break stationary alternative hypothesis. The results of the breakpoint unit root test are provided in Table 2, indicating that the unit root hypothesis can be rejected for all the series at a 5% significance level. Therefore, it can be concluded that all the variables are stationary.

Table 2. Breakpoint unit root test results

| Variable | Lag | Break Date | t-statistic | p-value |
|---|---|---|---|---|
| $s_t$ | 0 | 1999:10 | -13.01171 | <0.01 |
| $cre_t$ | 0 | 1990:12 | -15.88296 | <0.01 |
| $exc_t$ | 1 | 2001:03 | -14.00927 | <0.01 |
| $ip_t$ | 0 | 2020:06 | -23.09501 | <0.01 |
| $inf_t$ | 0 | 2002:01 | -13.56091 | <0.01 |

Both trend and break specifications are intercepts only. The break type is an additive outlier. The break selection method minimizes the Dickey–Fuller t-statistic. Appropriate lag length was selected using the Schwarz criterion for a maximum lag of 12 periods.

### 4.2. Bayesian Priors and Initial Settings

Since the prediction method used in this study is Bayesian, some a priori information must be entered into the system beforehand. The distributions of covariance matrices are assumed to have the following a priori:

$$\left(\Sigma_\beta\right)_i^{-2} \sim Gamma(10{,}0.01)$$

$$(\Sigma_h)_i^{-2} \sim Gamma(2{,}0.01)$$

$$(\Sigma_a)_i^{-2} \sim Gamma(2{,}0.01)$$

For initial values of time-varying parameters $\mu_{\beta_0} = \hat{\beta}_0, \mu_{a_0} = \hat{a}_0,\ \mu_{h_0} = log\hat{\sigma}_0^2$, and $\Sigma_{\beta_0} = \Sigma_{a_0} = \Sigma_{h_0} = 4 \times I$ were used. Here, $\hat{\beta}_0$, $\hat{a}_0$, and $\hat{\sigma}_0^2$ are estimates obtained by the least-squares method using learning data. Moreover, the 48 months of data between 1990:02 and 1994:01 were used as learning data. During the estimation of the model, 1,000 samples were set aside as the initial value, then M = 10,000 samples were drawn from a priori distributions, and the estimation stage was initiated (Nakajima et al. 2011).

### 4.3. Comparing Different VAR Specifications

In a VAR model, time variation can be realized in the coefficient matrix or the variance–covariance matrix. To accurately determine which structure governed the change over time in this study, four different specifications were compared:

- *VAR model with time-varying parameters and stochastic volatility (TVP-VAR-SV)*

- *VAR model with time-varying parameters and constant variance (TVP-VAR)*
- *Fixed coefficient VAR model with stochastic volatility (VAR-SV)*
- *VAR model with constant coefficients and constant variance (VAR)*

To compare the relative fit of a set of Bayesian models, the deviance information criterion (DIC) proposed by David J. Spiegelhalter et al. (2002) was used.

Table 3. DIC values for different VAR models

| **Models** | **DIC** | $\boldsymbol{p_d}$ | $\boldsymbol{\bar{D}}$ |
|---|---|---|---|
| TVP-VAR-SV | 6891.082 | 51.65845 | -3419.71 |
| TVP-VAR | 8385.601 | 44.58516 | -4170.51 |
| VAR-SV | 8580.96 | -353.51 | -4467.24 |
| VAR | 8624.85 | 44.38737 | -4290.23 |

Table 3 shows that the model with the lowest DIC value suggesting that it is more effective to use TVP-VAR-SV model. Here, $p_d$ is the effective number of parameters, quantifying the complexity of the model and reflecting the penalty for overfitting. Additionally, $\bar{D}$ represents the deviance, specifically $D(\bar{\theta})$, which is the goodness of fit of the model calculated at the posterior means of the parameters. This deviance is a crucial part of computing the DIC, with a lower deviance indicating a model that fits the data well. Moreover, the model with stochastic volatility exhibits a lower DIC value than the model with constant variance, underscoring the advantage of allowing SV to capture the dynamics more accurately. The lower DIC value for the SV model offers a more robust and flexible approach to understanding the time-varying impacts of monetary policy.

## 5. Empirical Results

To investigate how monetary policies implemented in Turkey between 1994 and 2020 have changed over time, equation (5) was estimated. In equation (5) $y_t = (s_t, cre_t, exc_t, ip_t, inf_t)'$ and $\beta_t$ is the lag matrix of vector $y_t$, with the lag order selected as 1, as suggested by the Bayesian information criterion. To further clarify the claim that Turkey experienced a price puzzle during 1994–2020, a classical VAR model estimation was performed using the CBRT policy rate instead of the interest rate spread in equation (5). The results obtained from this estimation are presented in Figure 1. This analysis aimed to demonstrate the unique responses of macroeconomic variables to shocks in monetary policy, providing critical insights into the dynamics determined within the specified period.

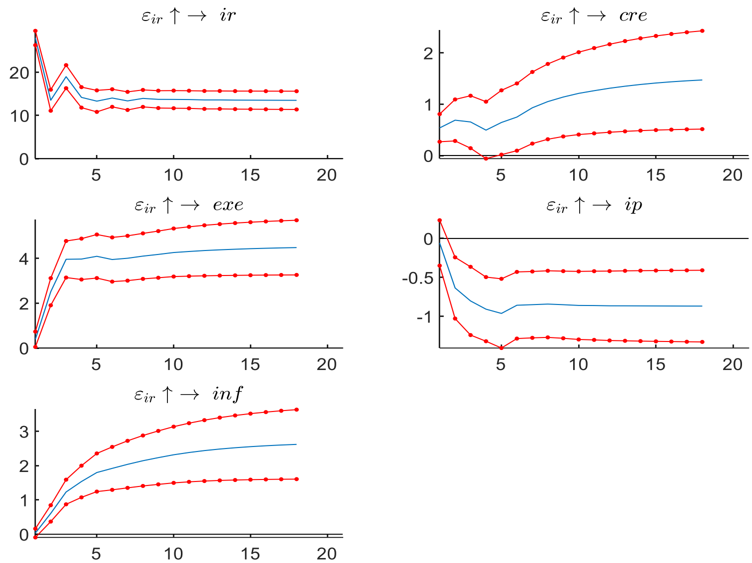



Figure 1. Responses of all variables to one standard deviation positive interest rate shock, with the red lines indicating the 95% confidence bands

Figure 1 illustrates that the response of inflation to an interest rate shock is positive. This is referred to as the price puzzle in the literature. From this perspective, using the overnight interest rate as a monetary policy instrument leads to an identification problem.

The classical VAR model results illustrated in Figure 1 reveal distinct puzzles that characterize Turkey's economic response to monetary policy shifts, notably the price puzzle. These findings highlight the complexities and unexpected behaviors in the macroeconomic variables when subjected to interest rate shocks, thus underscoring the limitations and challenges associated with using the overnight interest rate as a straightforward policy instrument. As we transition back to the TVP-VAR model, Table 4 presents the detailed estimations, including posterior means, standard deviations, 95% credible intervals, and inefficiency factors. Additionally, the convergence diagnostic (CD) statistics proposed by John Geweke (1992) for equation (5) are provided, facilitating a deeper and more dynamic understanding of how monetary policy impacts have evolved over time. This subsequent analysis allows us to capture the temporal variations in policy effectiveness that are not apparent in the static VAR framework.

Table 4. Estimation results for selected parameters in the TVP-VAR-SV model

| | Mean | Std. error | Lower (95%) | Upper (95%) | Inefficiency | CD statistics |
|---|---|---|---|---|---|---|
| $s_{b_1}$ | 0.0023 | 0.0003 | 0.0018 | 0.0028 | 18.6045 | 0.0988 |
| $s_{b_2}$ | 0.0023 | 0.0003 | 0.0018 | 0.0028 | 20.6426 | 0.0657 |
| $s_{a_1}$ | 0.0049 | 0.0012 | 0.0025 | 0.0072 | 78.8886 | 0.0520 |
| $s_{a_2}$ | 0.0055 | 0.0016 | 0.0022 | 0.0087 | 94.6970 | 0.6421 |
| $s_{h_1}$ | 0.6619 | 0.0807 | 0.5005 | 0.8233 | 28.1633 | 0.6917 |
| $s_{h_2}$ | 0.0115 | 0.0051 | 0.0012 | 0.0217 | 94.6970 | 0.6803 |

CD statistics, which indicate convergence to the posterior distribution, were found to be less than 1.96. Therefore, we concluded that the posterior distributions converged. Figure 2 shows the histogram of the distribution of the inefficiency factor of all parameters. All the factors are less than 100 (inefficiency factors for selected parameters are also relatively low in Table 4), indicating efficient sampling for the parameters in the TVP-VAR model (Nakajima et al. 2011).

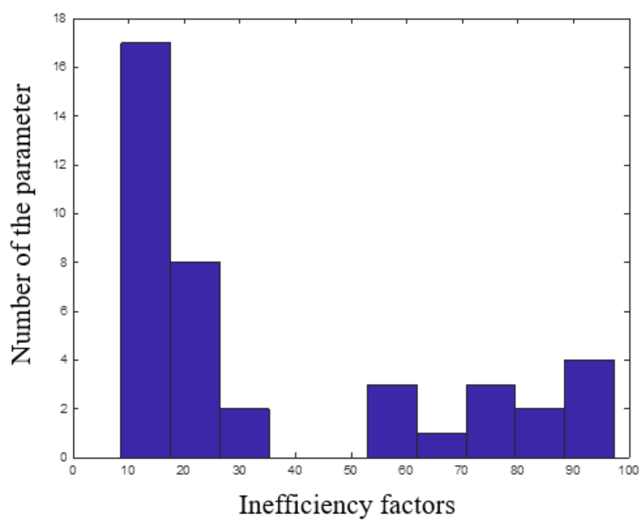



Figure 2. Histogram of inefficiency factors for all the parameter estimations

### 5.1. Time-varying volatility

Figure 3 plots the series for the estimated SV of the structural shock on our variable set, $(s_t, cre_t, exc_t, ip_t, inf_t)'$, based on the posterior mean and the 16th and 84th quantile intervals of the standard deviation of the shock, $r_{it} = exp(h_{it}/2)$.

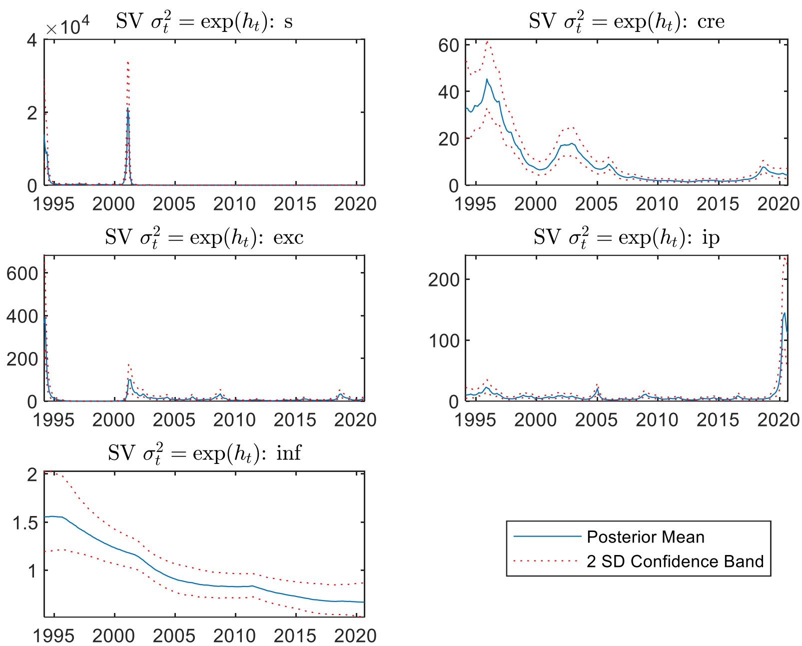



Figure 3. Posterior estimates for the SV of structural shocks, $r_{it} = exp(h_{it}/2)$, where solid lines represent posterior mean and the dotted lines represent 16th and 84th percentiles.

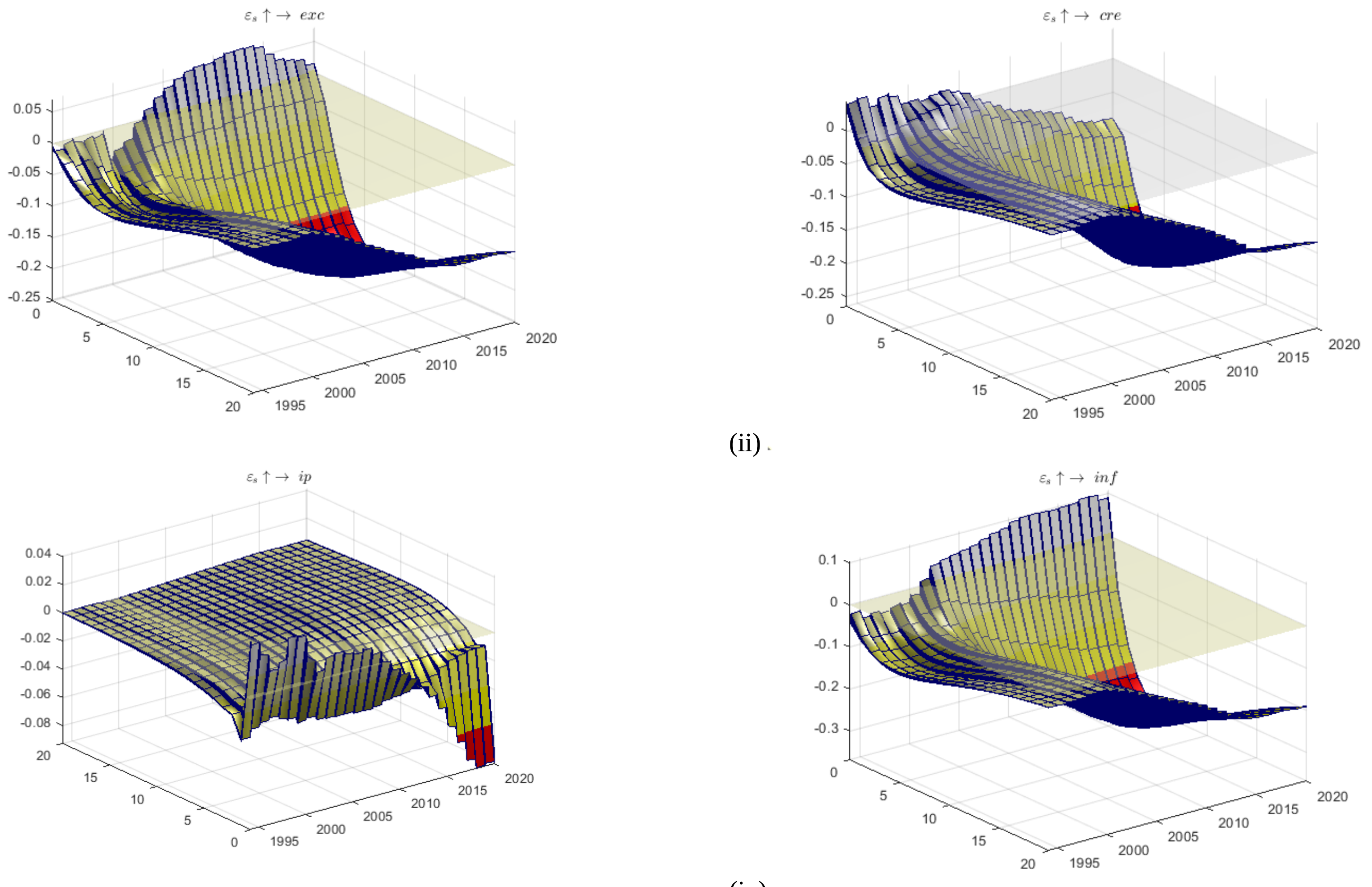
Figure 3(i) plots the time-varying volatility of interest rate spread. The volatility reached its highest value in 2001 due to the economic crisis. The time-varying volatility of credit in Figure 3(ii) reveals that volatility peaked in 1996 after the 1994 economic crisis and declined after 1996 since Turkey made the 16th stand-by arrangement with the IMF. Further, Figures 3(iii) and (iv) show the SV series for the exchange rate and the industrial production index, respectively. Exchange rate volatility peaked in 1994, after which it decreased and then rose again during the 2001 crisis. Both during the crisis periods in Turkey and in response, domestic demand for foreign exchange in the markets increased significantly. Finally, Figure 3(v) plots the stochastic volatility of inflation. The SV of inflation reached its maximum value in

1994 and then decreased. Hakan Berument, Yeliz Yalcin, and Julide Yildirim (2009) found similar results.

### 5.2. Time-Varying Impulse Responses

The model employed, due to its time-varying coefficient nature, allows the derivation of impulse response functions for each time point. Consequently, several different techniques have been used to report the resulting functions in graphical form. In Figure 4, three-dimensional graphs depict all the impulse response functions obtained for each time point on a single plot. This presentation method enables a detailed visualization of the changes in responses over time. Subsequently, in Figure 5, the focus is exclusively on the cumulative impulse and responses for the 18th period. Each point in these graphs represents the cumulative impulse response values calculated for this specific period. Furthermore, in Figures 6–9, the same type of graphical presentation is utilized, but the temporal aspects illustrated differ, showing the instantaneous, one-period delayed, and long-term impulse responses, respectively, with each approach providing a different perspective on the dynamics of the effects.

Figure 4 shows the general trends of the impulse response functions against interest rate spread shocks. Notably, the time-varying structure in all impulse responses aligned with economic expectations, while the empirical evidence suggests that tight monetary policy, measured by the interest rate spread defined herein, decreases inflation, the exchange rate, and domestic credit. Therefore, no price, exchange rate, or liquidity puzzle w found the results.




(i) (ii) (iii) (iv)

Figure 4. The responses of other variables to the monetary policy (spread) (three-dimensional impulse response graphs)

As Figure 4(i) shows, the responses of the exchange rate before 2000 remained weaker than those after 2000, and the magnitude of the exchange rate's response to the spread shock increased. Figure 4(ii) shows the response of credit. As expected, the responses to the shock in interest rate spread were negative, but these responses increased in absolute value. Moreover, the response of the credit rate became permanent after 2000. Figure 4(iii) shows that the instantaneous response of industrial production was positive and then turned negative after 2000. Moreover, it increased in absolute value after 2016. Finally, Figure 4(iv) shows that the response of inflation increased between 1994 and 2020. The instantaneous responses of inflation were negative but turned positive after 2008. This indicates that responses to the monetary policy shocks affected the market with a lag after 2008.

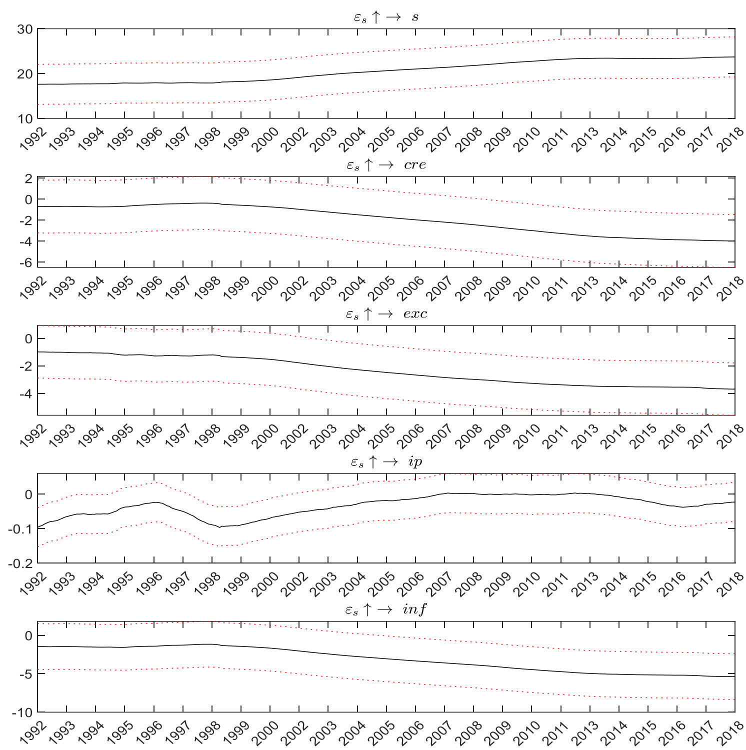



Figure 5. 18th-period cumulative impact response values against monetary policy shocks with ±2 standard error bands

Figure 5 shows the long-term policy effects with ±2 standard error bands. A standard deviation positive shock of interest rate spread causes declines in credit, exchange rate, and inflation in the long run, although it does not affect the industrial production index in the long run.

The effects of the interest rate spread shock on the exchange rate are depicted in Figure 6.

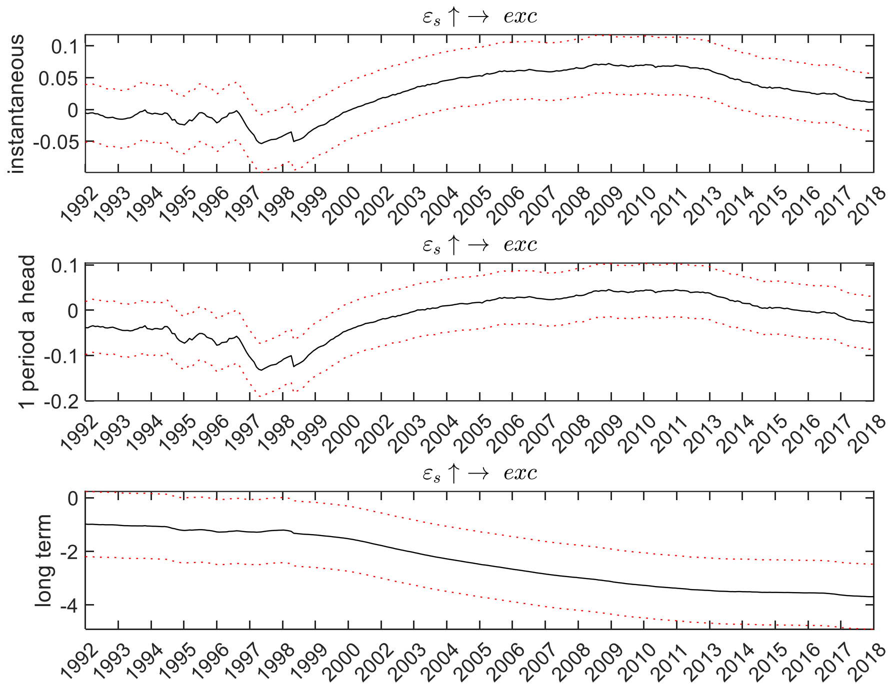



Figure 6. The time-varying responses of the exchange rate to monetary policy shocks

The time-varying response of the exchange rate to interest rate spread shocks was found to be statistically significant between 2007 and 2015. However, the magnitude of the instantaneous response reached its highest level in 2015. While the instantaneous responses were insignificant, long-term effects were statistically significant. This result indicates that expectations of the economic agents change over time (Rudiger Dornbusch, 1982). The long-term effects increased after the implementation of the stabilization program on December 9, 1999, and the Turkish lira began to increase in value excessively after January 2000.

In the spring of 2004, the expectation that the FED would raise interest rates became widespread. In developing countries such as Turkey, foreign investors sold their financial assets in the national currency they held in their portfolios and converted the assets they obtained into foreign currency. As a result of this increase in foreign exchange demand, the nominal exchange rate increase. During this period, the increase in spread did not have the desired effect on the exchange rate instantly.

Figure 7 illustrates the effects of a standard deviation positive shock in monetary policy on credit.

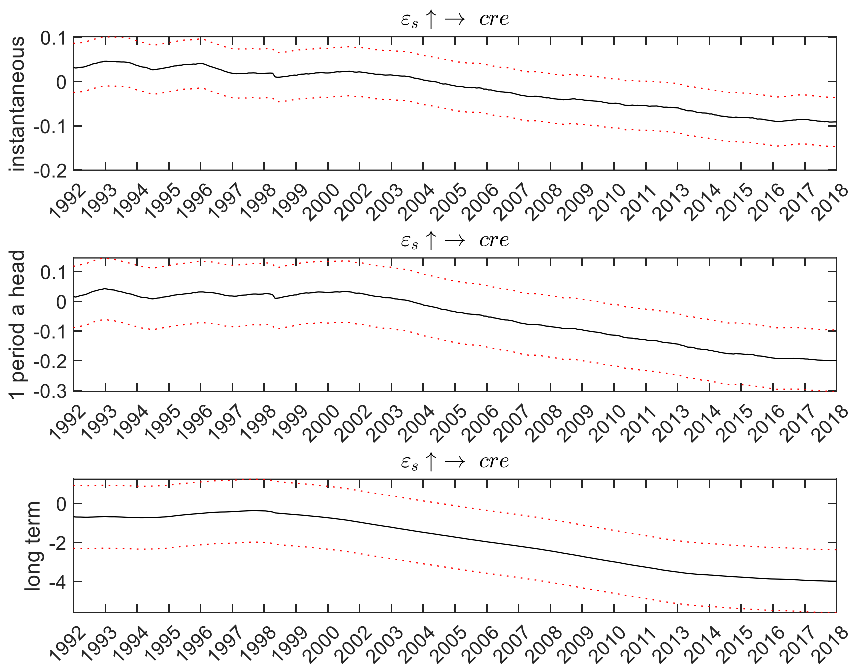



Figure 7. The time-varying responses of credit to monetary policy shocks

According to Figure 7, the response of credit to monetary policy shocks was negative and increased toward 2020. The instantaneous responses of credit became statistically significant after 2015, while the long-term cumulative effects became statistically significant after 2007. This pattern suggests an increased reactivity of credit availability to tightening monetary conditions over time. Such an increase in sensitivity may reflect deeper financial integration, more pronounced impacts of global economic conditions, and possibly enhanced effectiveness of monetary transmission mechanisms in recent years.

As Figure 7 shows, after 2007, the long-term effects of monetary policy began to have a more sustained and recognizable impact on credit behaviors as financial systems became more robust and interconnected. This is especially important as it indicates that monetary policy decisions have a lasting impact beyond immediate economic cycles.

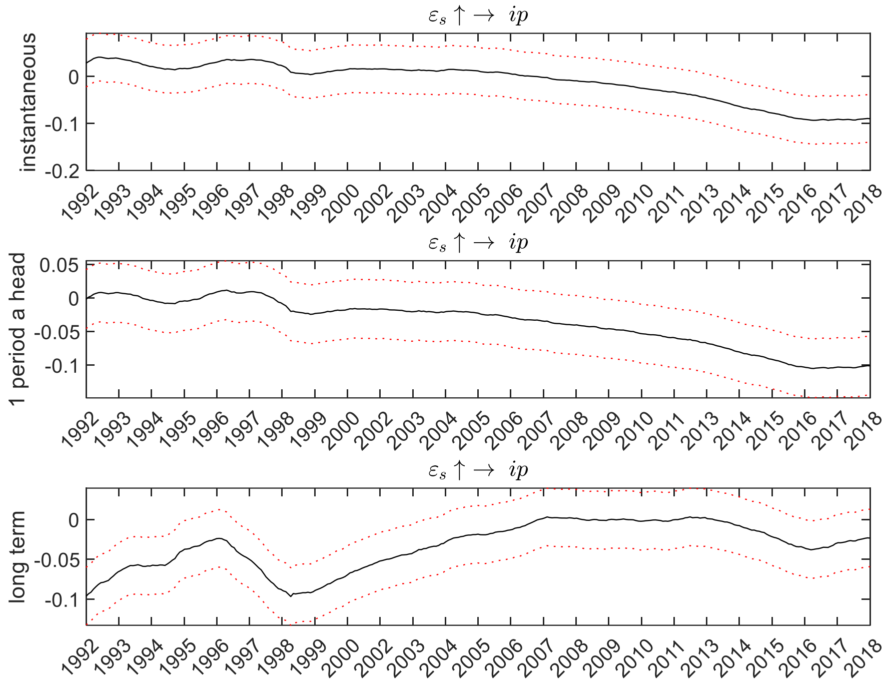



Figure 8. The time-varying responses of the industrial production index to monetary policy shocks

Figure 8 illustrates the response of economic activity to monetary policy shocks from 1992 to 2020, a period characterized by two distinct phases of monetary policy strategy. Initially, Turkey faced several severe economic crises from 1992 to 2004, promoting a monetary policy focused on immediate impacts to stabilize economic growth. During this period, the long-term effects of monetary policy on economic growth were statistically significant between 1992 and 1996 and again from 1997 to 2004, highlighting the Central Bank's emphasis on combating short-term economic downturns with responsive policy measures.

After 2004, as Turkey transitioned to a more stable economic environment, the Central Bank shifted its focus toward fostering sustainable growth through long-term policy impacts. This shift is evident in Figure 8, which presents a graph depicting the short-term effects of monetary policy becoming statistically significant after 2013, indicating a delayed but persistent impact of policy measures implemented during this more stable period.

The graph's three panels depict instantaneous, one-period ahead, and long-term responses, showing a clear evolution in the magnitude and direction of these effects over time. In the long-term panel, a notable trend shows the gradual increase in the responsiveness of economic activity to policy changes after 2013, suggesting that the effects of monetary policy became more pronounced and sustained as Turkey's economic policies matured.

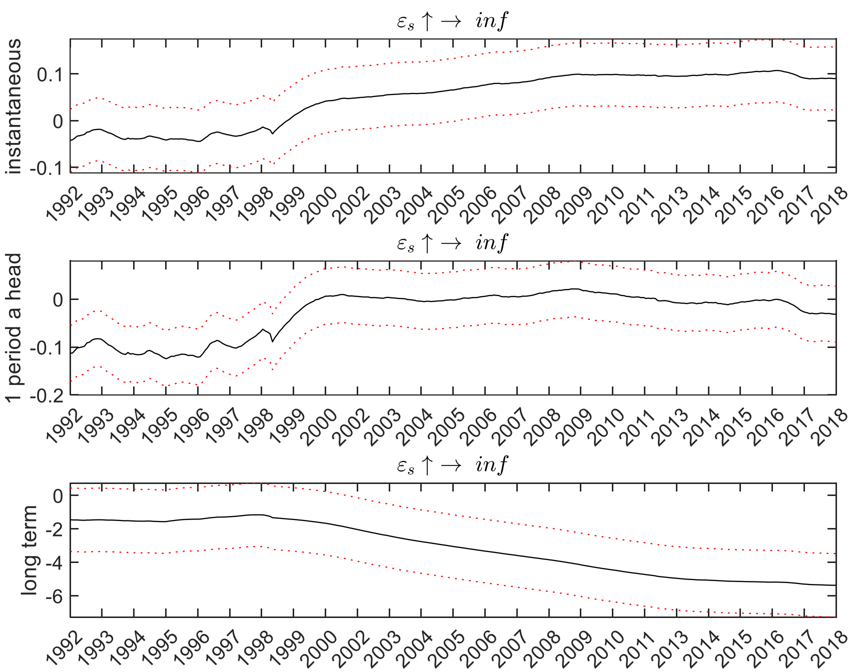



Figure 9. The time-varying responses of inflation to monetary policy shocks

Figure 9 shows the response of inflation to a tight monetary policy shock, which exhibited a time-varying structure. Impulse-response functions revealed two main trends over time. The response of inflation to a monetary policy shock has changed since the 2001 crisis (David M. Kotz, 2009), as after the 2001 crisis, the response of inflation increased to a tight monetary policy shock.

Due to Turkey's political uncertainties and crises between 1994 and 2001, regular and determined economic policies could not be implemented. For this reason, the monetary policy implemented during this period had little influence on inflation. The instantaneous effects on inflation before 2001 was not found to be statistically significant. The effects of monetary policies on inflation increased with the Transition to a Strong Economy program. Moreover, inflation instantaneously responds positively after 2009, indicating that the cost channel became effective after 2009.

The instantaneous effect of the cost channel ended after one period, and the lagged response of inflation to the monetary policy shock was found to be negative. In other words, the tight monetary policy implemented by the CBRT can only have the necessary effect on inflation after one period. Once again, the impact of the Central Bank's monetary policy in the pre-2001 period was found to be statistically significant in the short term, whereas the long-term effects were found to be statistically insignificant. The impact of the monetary policy implemented by the CBRT after 2001 emerged in the long term (Nezir Kose, Furkan Emirmahmutoglu, and Sezgin Aksoy, 2012).

## 6. Conclusion

This study examined how the effects of monetary policy on macroeconomic variables in Turkey have changed over time using a TVP-VAR-SV model for the period from February 1994 to September 2020. The interest rate spread was used as the measure of monetary policy due to the separation of the relationship between bank and policy interest rates.

The evidence indicates that the responses of inflation, industrial production, exchange rates, and credit changed over time. Following the exchange rate crisis that began in 2017, confidence in monetary policy began to decline (Orhangazi, 2020). Moreover, oncreased perceived risks for the Turkish economy appeared to amplify the effects of monetary policy shocks. Before the 2001 economic crisis, monetary policy shocks did not significantly affect the exchange rate; however, the magnitude of the responses in economic activity increased after 2016. During this period, interest rate announcements made by the FED caused capital outflows from all developing countries. The impact of monetary policy on economic growth intensified due to existing fragilities. Additionally, while the short-term responses of economic activity to monetary policy shocks were statistically significant, the long-term effects were not. After the global crisis, monetary policy had a short-term impact on economic activity.

The response of inflation to monetary policy between 1994 and 2020 exhibited a time-varying structure. Different monetary policy approaches produced varying effects on inflation. Moreover, the response of inflation to monetary policy shocks was found to be lower from 1994 to 2001 than from 2002 to 2020. After 2001, the response of inflation to monetary policy implications increased after 2001. The political uncertainties and crises in Turkey between 1994 and 2001 hindered the consistent implementation of established economic strategies, such as stabilization programs, structural reforms, and inflation control, rendering monetary policy less effective against inflation. Following the implementation of the Transition to a Strong Economy program, the impact of monetary policies on inflation became more pronounced. Interestingly, despite expectations of decreasing inflation with stringent monetary policies post-2009, the observed outcomes were contrary.

This situation indicates that the cost channel is effective in the Turkish economy, positing that monetary policy affects not only demand but also supply, based on the premise that the decrease in supply is greater than the decrease in demand. With the global crisis, the amount of commercial credit utilized by companies in Turkey continued to increase annually. By 2020, the volume of commercial credit was 667% higher than in 2009. This can be viewed as an indicator of the cost channel's effectiveness, as it relates to the critical elements for companies.

The production costs of companies are proportional to their ability to secure financing. If companies lack the necessary capital for production, they can obtain it through loans from banks. High credit rates contribute to increased costs for companies. However, the effects of the cost channel become insignificant within one period and, subsequently, turn negative, as expected. In other words, the tight monetary policy implemented can only exert the necessary effect on inflation after one period. The results of the implemented monetary policy become evident in the long run.

This study's findings reveal critical policy implications for Turkey. The time-varying effects of monetary policy highlighted in this analysis suggest that Turkish policymakers should adopt a more flexible approach, particularly in response to Turkey's unique economic fluctuations and crises, such as those experienced during the post-2001 economic reforms and the 2018 currency crisis. The evolving response of macroeconomic variables to policy shifts underscores the need for Turkey to maintain dynamic policy frameworks that are responsive to new economic data and shifts in global and domestic economic conditions. Furthermore, the significant impact of interest rate spreads on inflation and economic activity indicates that Turkish monetary authorities should closely monitor various measures of monetary policy. This could serve as a key indicator of the broader impacts of their decisions, especially during periods of heightened market volatility.

To enhance economic stability and mitigate adverse effects during volatile periods, it is crucial to understand the mechanisms through which policy adjustments influence macroeconomic variables. For instance, exploring the cost channel post-

2009 provides insights into how monetary policy adjustments can inadvertently affect inflation rates, especially during times of economic fragility. This understanding could inform strategies aimed at buffering the economy against such unintended consequences.

Future research could further investigate the sectoral impacts of monetary policy changes in Turkey, examining how different sectors adjust to policy shifts over time. This could provide more granular insights into the transmission mechanisms of monetary policy within the Turkish economy and assist in designing targeted interventions that support sustainable growth and stability.

## Declarations

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Ethical Standards** Ethical review and approval were not required for the paper.

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