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No.24-E-18
December 2024

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Macroeconomic Impact of Shifts in Long-term Inflation Expectations [*]

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December 2024

Abstract

This paper examines the impact of shifts in long-term inflation expectations on economic activity and price dynamics in Japan using a time-varying parameter vector autoregressive (TVP-VAR) model. Our empirical findings demonstrate that exogenous positive shocks to long-term inflation expectations improve the output gap and generate upward pressure on inflation rates. These results suggest the existence of an "expectations channel" in Japan, whereby higher inflation expectations stimulate private sector spending through mechanisms such as reducing real funding costs. Looking at the analysis by period, it indicates that during the deflationary phase of the 2000s, declining long-term inflation expectations likely contributed to persistent downward pressure on prices, potentially serving as one factor that hindered Japan's exit from sustained deflation. However, following the introduction of the "price stability target" and Quantitative and Qualitative Monetary Easing (QQE) in 2013, this contribution reversed, appearing to exert upward pressure on inflation rates. In this respect, the findings suggest that the "management of expectations" intended by monetary policy during this period demonstrated some effectiveness. Nevertheless, as inflation rates subsequently declined, the upward contribution of inflation expectations to the inflation rate diminished, failing to anchor expectations to the price stability target. This outcome suggests the inherent difficulty in maintaining a sustained influence on long-term inflation expectations.

JEL Classification: C32, E31, E52
Keywords: Inflation Expectation, Inflation, TVP-VAR, Monetary Policy

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[*]The authors are grateful to Ichiro Fukunaga, Yuichiro Ito, Sophocles Mavroeidis, Jouchi Nakajima, Koji Nakamura, Etsuro Shioji, Yosuke Takeda, participants of the second workshop on the "Review of Monetary Policy from a Broad Perspective" entitled "Economic Activity, Prices, and Monetary Policy over the Past 25 Years," and the staff at the Bank of Japan. Any remaining errors are the authors' own. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of Japan.

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1. Introduction

In Japan, the natural rate of interest experienced a secular decline following the collapse of the asset price bubble in the early 1990s, driven by factors including a downward shift in growth expectations, financial system instability, and structural economic changes associated with globalization and demographic aging. By the late 1990s, nominal short-term interest rates had reached the effective lower bound (ELB).[1] During subsequent policy discussions regarding appropriate monetary policy responses under the ELB, particular attention was focused on the management of inflation expectations. Krugman (1998), who pioneered this discourse, argued that to address the "liquidity trap" under the ELB, central banks could effectively stimulate the economy by setting inflation targets to raise inflation expectations, thereby lowering real interest rates. As price stability remained a critical challenge in Japan, various unconventional monetary policy instruments were implemented from the late 1990s onward. Following the adoption of the "price stability target" of 2% in 2013, the introduction of Quantitative and Qualitative Monetary Easing (QQE)[2] emphasized the significance of monetary policy transmission through inflation expectations—the "expectations channel".[3] The expectations channel under QQE was designed to provide accommodative effects on business investment and private consumption not only by maintaining low nominal interest rates but also by reducing real interest rates through elevated inflation expectations.

From developments in Japan's long-term inflation expectations over the past 25 years,[4] the following observations can be made (Figure 1). From the late 1990s, as nominal interest rates faced the ELB constraint, private sector long-term inflation expectations gradually declined. While there was a temporary rise in inflation expectations around 2006, initiated by commodity price increases, the expectations again declined during the economic downturn triggered by the global financial crisis. Following the introduction of the "price stability target" in 2013, inflation expectations reversed course upward. However, as realized inflation rates decreased due to factors such as falling oil prices, strong adaptive expectation formation mechanisms led inflation expectations to decline and subsequently stabilize around 1%. Since 2020, inflation expectations have increased, reflecting rising energy and food prices in the post-COVID-19 environment and tightening labor market conditions.

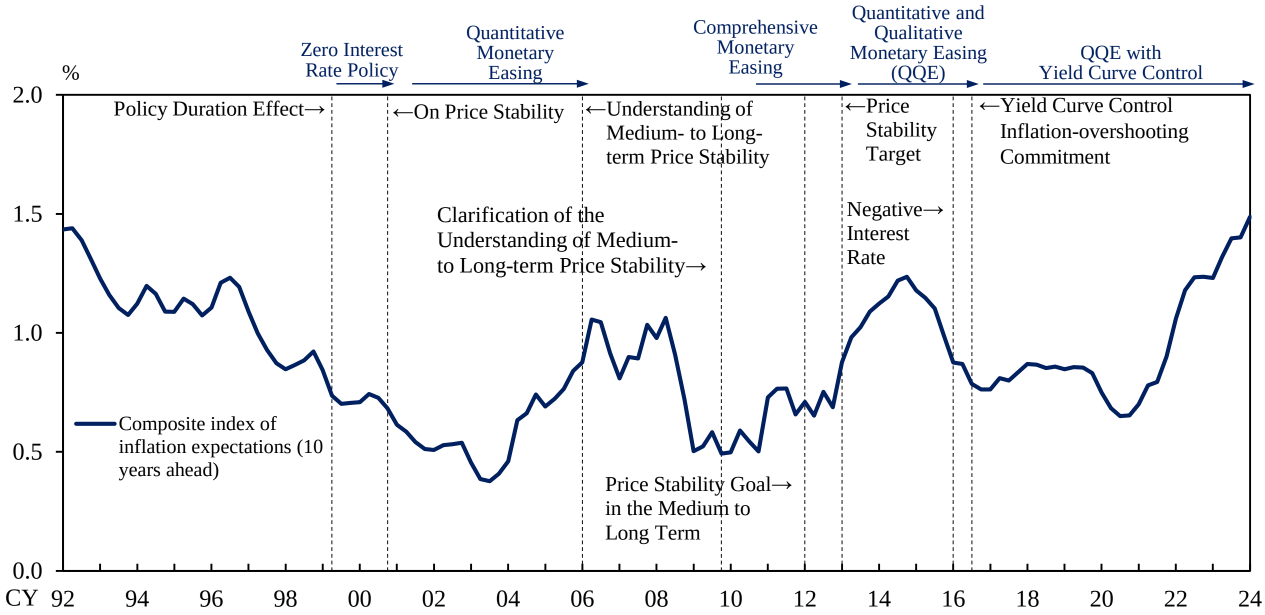
[1] For recent trends in measuring Japan's natural rate of interest, see Nakano et al. (2024).

[2] The effects on long-term interest rates expected under QQE are discussed in Hirata et al. (2024).

[3] Regarding the role of the expectations channel in QQE, see, for example, Kuroda (2015).

[4] Inflation expectations have distinct characteristics depending on economic agent type and time horizon. Osada and Nakazawa (2024) attempt to aggregate these into a single indicator by extracting common components using principal component analysis from household, corporate, and professional inflation expectations. For details of the methodology, see Osada and Nakazawa (2024).

Figure 1: Long-term inflation expectations and monetary policy



Note: Composite index of inflation expectations (10 years) represents common components extracted through principle components analysis of inflation expectations from households, firms, and professional forecasters (following Osada and Nakazawa, 2024).

Sources: Bank of Japan; Bloomberg; Consensus Economics inc.,"Consensus Forecasts"; QUICK, "QUICK Monthly Market Survey <Bonds>."

Overall, the 25-year period shows significant fluctuations in inflation expectations amid the implementation of various unconventional monetary policy instruments. Examining how these variations in long-term inflation expectations have influenced production and prices represents a crucial consideration in understanding monetary policy transmission mechanisms.

Based on these observations, this paper analyzes the role of long-term inflation expectations in the Japanese economy. Specifically, we examine the extent to which fluctuations in inflation expectations have been a significant factor in explaining Japan's production and price dynamics, and the degree to which changes in expectations have been influenced by monetary policy. Our analytical framework employs a time-varying parameter vector autoregressive (TVP-VAR) model that incorporates long-term inflation expectations, the output gap, inflation rate, and shadow rate as endogenous variables. By incorporating time-varying parameters, we attempt to capture the impact of inflation expectations on production and prices while accounting for potential secular changes in economic structure. Additionally, using our estimated model, we evaluate the effects of the introduction of "price stability target" on long-term inflation expectations and inflation rates. Notably, we employ the shadow rate as a proxy for monetary policy, enabling us to capture the effects of both conventional interest rate policy and various unconventional monetary policy measures.

Our key findings are as follows. First, in Japan, positive shocks to long-term inflation expectations improve the output gap and generate upward pressure on inflation rates. This suggests the possibility that increases (decreases) in long-term inflation expectations operated through decreases (increases) in real interest rates, leading to increases (decreases) in private sector consumption and investment. Second, examining specific periods, during the deflationary phase of the 2000s, declining inflation expectations likely functioned as one factor to hinder Japan's exit from sustained deflation by exerting continuous downward pressure on prices. Following the introduction of the "price stability target" and QQE in 2013, this contribution reversed, exerting upward pressure on realized inflation rates (year-on-year rate of change in the CPI). In this respect, the "management of expectations" intended by monetary policy during this period appears to have achieved some measure of effectiveness. However, as inflation rates subsequently declined, the upward contribution from inflation expectations diminished, failing to anchor expectations to the price stability target of 2%. This suggests the inherent difficulty in maintaining a sustained influence on long-term inflation expectations. Furthermore, examining the shadow rate's response to shocks that increase (decrease) long-term inflation expectations reveals no statistically significant response in Japan, while it tends to respond with monetary tightening (easing) in U.S. This difference may reflect the contrasting monetary policy responses between the U.S., where long-term inflation expectations are generally anchored to the inflation target, and Japan, which faced prolonged deflation and low inflation under the ELB constraint.

The paper is organized as follows. Section 2 surveys existing literature analyzing the relationship between changes in inflation expectations, economic activity, prices, and monetary policy. Section 3 details the data and TVP-VAR model framework we used. Section 4 presents and discusses our analytical findings. Section 5 concludes.

2. Literature Review

This paper relates to previous literature addressing two key areas: (1) the impact of changes in long-term inflation expectations on economic activity and prices, and (2) the formation mechanisms of long-term inflation expectations — particularly the role of central bank communications and monetary policy responses. This section reviews relevant literature and establishes our paper's contribution.

First, regarding the impact of changes in long-term inflation expectations on economic activity and prices, empirical research has been accumulating in recent years (Armantier et al., 2015; Coibion et al., 2020a, etc.). A notable example is Coibion et al. (2022), who conducted a randomized control trial (RCT) with U.S. households, demonstrating that households with elevated inflation expectations significantly increased their consumption expenditure over subsequent months.[5] Concerning firms' inflation expectations and behavior, Coibion et al. (2020b) used survey data from Italian firms to conclude that changes in inflation expectations can influence firms' investment and employment decisions. Kaihatsu and Shiraki (2016) reported that in Japan, increases in firms' long-term inflation expectations raise wage growth rates and short-term inflation expectations, while increases in short-term inflation expectations without corresponding increases in long-term inflation expectations tend to decrease wage growth rates and operating profit margins. Łyziak and Sheng (2023) noted that while professional forecasters do not directly engage in spending behavior, their inflation expectations can influence the real economy through household behavior when households reference professional forecasts in forming their own expectations. Regarding the impact of inflation expectations on price dynamics, Fuhrer (2012), studying the U.S., argued that fluctuations in long-term inflation expectations influence inflation rates through changes in short-term inflation expectations.

Second, regarding the formation mechanisms of inflation expectations, various theories have been proposed, including the sticky information hypothesis and rational inattention hypothesis, though no clear consensus exists (Bernanke, 2007; Yellen, 2016; Coibion et al., 2018). A characteristic feature in Japan is the strongly adaptive nature of inflation expectations, which are highly responsive to realized inflation (Nishino et al., 2016). Factors potentially influencing inflation expectations include inflation targeting policies and central bank credibility (Bernanke, 2017; Fukuda and Soma, 2019), and past inflation experience and norms (Malmendier and Nagel, 2016; Cavallo et al., 2017; Diamond et al., 2020). Additionally, research indicates that under low inflation, economic agents tend to pay less attention to price dynamics, resulting in inflation expectations remaining stable at low levels (Bracha and Tang, 2022; Weber et al., 2024).[6] These factors may have operated relatively

[5] Multiple theoretical channels exist through which inflation expectations can influence consumption. First, rising inflation expectations can generate intertemporal substitution effects through lower real interest rates. In this case, higher inflation expectations lead to increased current real consumption expenditure. Additionally, if higher inflation expectations lead to expectations of lower future real income, they may suppress real consumption. Furthermore, if changes in inflation expectations are linked to future economic outlook, they may influence spending behavior through changed perceptions of future unemployment risk. On this point, Ito and Kaihatsu (2016) reported that since the implementation of QQE in Japan, the consumption-boosting effect through lower real interest rates has exceeded the consumption-suppressing effect through lower expected real income, indicating that higher inflation expectations contributed to increased real consumption. Additionally, Lieb and Schuffels (2022) noted that changes in inflation expectations affect the present discounted value of assets and liabilities, suggesting that consumption behavior responses may vary depending on household asset composition.

[6] Using online survey data, Kikuchi and Nakazono (2023) confirmed that over half of Japanese households collect CPI information less frequently than quarterly, and show relatively low interest in price trends for non-food goods and services.

strongly in Japan, given its prolonged period of low inflation.[7] Building on the literature, Fukunaga et al. (2024b) analyzed Japan's long-term inflation expectation formation mechanisms using the Bank of Japan's large-scale macroeconomic model, Q-JEM (Quarterly Japanese Economic Model). They found that while forecasting functions incorporating adaptive expectations mechanisms generally demonstrate higher predictive accuracy, the relative performance of different specifications varies by period, indicating high uncertainty in inflation expectation formation in Japan.

Regarding monetary policy, numerous studies have emphasized central bank communication as an important element influencing expectation formation (Blinder et al., 2008). Traditionally, its importance was emphasized in the context of appropriate communication about the central bank’s future outlook helping to suppress excessive fluctuations in financial markets and economic variables. Subsequently, as nominal interest rates faced the ELB constraint, attention focused on influencing inflation expectations. This argument was pioneered by Krugman (1998), who argued for the necessity of raising inflation expectations through inflation targets to address the liquidity trap.

However, skeptical views exist regarding such effects, including research showing that both households' and firms' inflation expectations become less responsive to monetary policy announcements in low-inflation environments (Coibion et al., 2020a), and arguments emphasizing the difficulty of managing expectations as intended while maintaining credibility under liquidity trap conditions (Sims, 2004; Hattori et al., 2021). Additionally, Gertler and Karadi (2015) reported no significant response in long-term inflation expectations to monetary policy shocks in the U.S.[8] As discussed above, the relationship between inflation expectations and monetary policy has been the subject of various debates and research throughout different periods.

Some studies have employed VAR models with the same four endogenous variables as our paper—inflation expectations, output, prices, and shadow rates (Diegel and Nautz, 2021; Neri, 2023). Diegel and Nautz (2021) estimated a four-variable VAR model including long-term inflation expectations for the U.S., and analyzed the response of the expectations to

[7] Under adaptive expectation formation mechanisms, current price and wage shocks can strongly influence long-term inflation expectations. For example, as noted by Fukunaga et al. (2024a), if foreign-originated negative shocks exert persistent downward pressure on Japan’s CPI, this may suppress inflation expectations through adaptive expectation formation. Additionally, Aoki et al. (2023) suggested that Japanese firms' wage suppression tendencies through wage markdowns may have contributed to stagnant inflation expectations.

[8] There is no clear consensus in empirical research regarding whether monetary policy can significantly influence long-term inflation expectations. While Gertler and Karadi (2015) found negative results, Gambetti and Musso (2017) indicated that ECB asset purchases slightly raised long-term inflation expectations in the eurozone, and Jarociński and Karadi (2020) concluded that monetary tightening significantly reduces medium to long-term inflation expectations.

monetary policy shocks and their role in policy transmission. They confirmed that positive shocks to inflation expectations lead to decreased unemployment and increased inflation rates. They also found that monetary tightening significantly lowers long-term inflation expectations, amplifying the policy effects on economic activity and prices. Neri (2023) applied a similar four-variable VAR model to the euro area, finding that endogenous policy rate cuts in response to declining inflation expectations limit the transmission to inflation rates. Furthermore, by comparing identified structural shocks with ECB press conference communications, the study provided additional insights into which communications influence private sector inflation expectations.[9]

To our knowledge, no VAR model analysis for Japan has incorporated long-term inflation expectations as an endogenous variable while allowing for time-varying economic structure.[10] Diegel and Nautz (2021) for the U.S. and Neri (2023) for the euro area did not allow for time-varying parameters. Our paper analyzes the impact of long-term inflation expectation fluctuations on macroeconomic variables in Japan while accounting for structural changes in the economy.

3. Estimation Method and Data

We employs a time-varying parameter vector autoregressive (TVP-VAR) model that allows for temporal variation in both parameters and error term variances. The model comprises four endogenous variables: long-term inflation expectations, output gap, inflation rate, and shadow rate. For comparative analysis between Japan and the U.S., we apply models with identical structures to both countries.

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[9] Additional empirical research examining the relationship between unconventional monetary policy and private sector expectations includes Anzuini and Rossi (2022). Analyzing the U.S., they empirically investigated the impact of central bank asset purchases and forward guidance on economic agents' expectations. Their results indicate that asset purchases, in particular, have strong effects on private sector expectations.

[10] While not including inflation expectations as an endogenous variable, De Michelis and Iacoviello (2016) attempted to empirically evaluate the effects of the introduction of Japan's "price stability target" through innovative identification restrictions. They estimated a five-variable VAR comprising inflation rate, output gap, real effective exchange rate, year-over-year oil prices, and bank lending rates, using long-run restrictions to extract inflation target shocks. Specifically, they imposed constraints whereby such shocks (i) have equal long-term effects on inflation rates and lending rates, and (ii) do not affect the output gap. Additionally, Nakajima et al. (2010) empirically examined monetary policy commitment effects using a TVP-VAR model with four variables: inflation rate, output, overnight call rate, and private sector expectations of future economic conditions. However, for expectation variables, they used household living conditions expectations and the diffusion index (DI) series of the forecast for business conditions from the Short-Term Economic Survey of Enterprises in Japan (the *Tankan*.)

3.1. Estimation method

This section outlines the TVP-VAR model used for estimation. Vector autoregressive (VAR) models are widely employed in empirical monetary policy analysis to describe relationships between multiple economic variables. The simplest VAR models assume that parameters governing economic variable relationships and error term variances remain constant over time, precluding consideration of temporal changes in economic structure. In contrast, this paper employs a TVP-VAR model that allows for temporal variation in both parameters and error term variances to account for potential changes in economic structure.[11]

Consider a VAR(p) model where parameters depend on time t:

$$Y_t = B_{0,t} + B_{1,t}Y_{t-1} + \cdots + B_{p,t}Y_{t-p} + u_t \tag{1}$$

where Y_t is the observed variable vector comprising four variables, $Y_t \equiv [y_t, \pi_t, r_t, \pi_t^e]'$. Here, y_t, π_t, r_t, and π_t^e represent the output gap, inflation rate, shadow rate, and long-term inflation expectations, respectively. $B_{0,t}$ is the intercept vector, $B_{1,t}, \dots, B_{p,t}$ are coefficient matrices, and u_t is the reduced-form residual. This equation can be simplified as:

$$Y_t = X'_t\theta_t + u_t \tag{2}$$

where θ_t represents the concatenated column elements of $B_{0,t}, \dots, B_{p,t}$ and $X_t = I_p \otimes (1, Y'_{t-1}, \dots, Y'_{t-p})'$ is defined using the Kronecker product. The time-varying parameter vector θ_t is assumed to follow the dynamics:

$$p(\theta_t|\theta_{t-1}, Q) = I(\theta_t)f(\theta_t|\theta_{t-1}, Q) \tag{3}$$

where $I(\theta_t)$ on the right-hand side is an indicator function that rejects non-stationary VAR systems, serving to reject parameter combinations that would result in non-stationary VAR systems (Cogley and Sargent, 2005; Baumeister and Peersman, 2013). Additionally, $f(\theta_t|\theta_{t-1}, Q)$ is given by the following random walk process:

$$\theta_t = \theta_{t-1} + \nu_t, \qquad \nu_t \sim N(0, Q) \tag{4}$$

Here, Q represents the variance of temporal variation in the time-varying parameters.

For the reduced-form residuals (u_t) in equation (2), we make the following assumption under zero mean and time-varying covariance matrices:

$$Var(u_t) = A_t^{-1}\Omega_t(A_t^{-1})'$$

[11] See Nakajima (2011) for a comprehensive survey of TVP-VAR.

where A_t and Ω_t are time-varying matrices, with A_t assumed to be a lower triangular matrix with all diagonal elements equal to one, and Ω_t assumed to be a diagonal matrix, respectively:

$$A_t \equiv \begin{bmatrix} 1 & 0 & 0 & 0 \\ \alpha_{21,t} & 1 & 0 & 0 \\ \alpha_{31,t} & \alpha_{32,t} & 1 & 0 \\ \alpha_{41,t} & \alpha_{42,t} & \alpha_{43,t} & 1 \end{bmatrix}, \Omega_t \equiv \begin{bmatrix} \sigma_{1,t} & 0 & 0 & 0 \\ 0 & \sigma_{2,t} & 0 & 0 \\ 0 & 0 & \sigma_{3,t} & 0 \\ 0 & 0 & 0 & \sigma_{4,t} \end{bmatrix} \tag{5}$$

Under these conditions, we assume each matrix element follows a random walk process:

$$\alpha_{ij,t} = \alpha_{ij,t-1} + \zeta_{ij,t} \tag{6}$$

$$ln(\sigma_{i,t}) = ln(\sigma_{i,t-1}) + \eta_{i,t} \tag{7}$$

where $\zeta_{ij,t} \sim N(0, S_{ij})$ and $\eta_{i,t} \sim N(0, w_i)$. S_{ij} and w_i represent the variances of temporal variation in the matrix elements of A_t and Ω_t, respectively. Finally, we assume that $\nu_t, \zeta_{ij,t}$ and $\eta_{i,t}$ in equations (4), (6), and (7) are independent of each other. Parameters are estimated using Markov Chain Monte Carlo (MCMC) methods based on Bayesian techniques. Prior distributions for parameters are set following Benati and Mumtaz (2007) (see Appendix A for details of the algorithms). Following previous studies such as Primiceri (2005) and Benati (2008), we select a lag order of two periods for the TVP-VAR.

3.2. Data

The estimated TVP-VAR model comprises four endogenous variables: output gap, inflation rate, shadow rate (as a proxy for monetary policy), and long-term inflation expectations. The sample period covers from 1983/Q1 to 2023/Q4 for both Japan and the U.S.

For Japan's estimation, we used the Bank of Japan's estimates for the output gap,[12] and year-on-year rate of change in the consumer price index (CPI, excluding fresh food and the effects of consumption tax hikes) for the inflation rate. The shadow rate was employed as a proxy for monetary policy to capture the effects of both conventional interest rate policy and various unconventional monetary policy measures. Specifically, we used the shadow rate based on methodology proposed by Krippner (2015), which is estimated in Hirata et al. (2024) for Japan.[13] The shadow rate, which aggregates information from the entire yield curve, has recently gained prominence as a proxy indicator for monetary policy,

[12] See Kawamoto et al. (2017) for specific estimation methodology.

[13] Shadow rate estimates based on Krippner (2015) are also used in studies such as Diegel and Nautz (2021). For the Japanese model, we conducted robustness checks using shadow rates based on Wu and Xia (2016) and Imakubo and Nakajima (2015) methodologies, confirming that results remain qualitatively unchanged.

encompassing unconventional policy measures such as asset purchases and forward guidance (Lemke and Vladu, 2016; Ichiue and Ueno, 2018; Avdjiev et al., 2020; Diegel and Nautz, 2021; Jones et al., 2021; Koeda and Wei, 2023). For long-term inflation expectations, we used the "composite index of inflation expectations (10-year)" developed by Osada and Nakazawa (2024).

For the U.S. estimation, we used the deviation rates between real GDP and potential GDP for the output gap.[14] The inflation rate is measured by year-on-year changes in the CPI, the shadow rate is estimates based on Krippner (2015), and long-term inflation expectations are based on surveys conducted by the Philadelphia Fed (10-year).

3.3. Structural shock identification

As with fixed-parameter VAR models, the residuals (u_t) obtained from the reduced-form TVP-VAR model are correlated with each other and do not represent independent structural shocks. Therefore, we need to identify structural shocks (ϵ_t) by assuming the following relationship:

$$\epsilon_t = \Xi_t u_t \tag{8}$$

To specify matrix Ξ_t—to identify structural shocks—we employ short-term sign restrictions following Diegel and Nautz (2021) and Neri (2023).[15] Specifically, we assume four structural shocks: demand shock (ϵ^{DM}), supply shock (ϵ^{SP}), interest rate shock (ϵ^{MP}), and inflation expectation shock (ϵ^{EX}), with the following assumed responses of each variable to these shocks (Table 1).

In the table, "+" indicates responses in the same direction as the shock, "-" indicates responses in the opposite direction, and blank cells indicate no restrictions. For demand and supply shocks, we impose restrictions similar to those used in previous studies such as Peersman (2005), and Benati (2008). Specifically, we assume demand shocks are structural shocks that move inflation rates and output gaps in the same direction, while supply shocks are those that move these variables in opposite directions. In other words, positive (negative) demand shocks trigger inflation rate increases (decreases) due to demand expansion (contraction), while positive (negative) supply shocks cause demand contraction (expansion) due to inflation rate increases (decreases) driven by supply factors such as oil price surges. Interest rate shocks are structural shocks capturing exogenous changes in shadow rates and

[14] Following Diegel and Nautz (2021), the output gap (gap) is calculated as $gap = 100 * \ln(y/y^*)$, using Congressional Budget Office (CBO) potential GDP (y^*) estimates and real GDP (y).

[15] Related research identifying TVP-VAR structural shocks using sign restrictions includes Benati and Mumtaz (2007), Canova and Gambetti (2009), Hofmann et al. (2012), and Baumeister and Peersman (2013).

Table 1: Sign-restrictions

Variables	Structural shocks			
	Demand	Supply	Interest rate	Inflation expectation
Output gap	+	-	-	
Inflation rate	+	+	-	
Shadow rate			+	
Inflation expectation				+

can be interpreted as effects that alter the entire yield curve through both conventional and unconventional monetary policy instruments. Here, we assume that structural shocks that increase (decrease) shadow rates lead to decreases (increases) in output gaps and inflation rates. Note that sign restrictions are imposed only at the time the shock occurs.

Inflation expectation shocks are the primary structural shocks of interest in this analysis. However, in our identification restrictions, we impose no substantial constraints beyond normalizing their signs. Therefore, from an identification perspective, these represent "shocks capturing long-term inflation expectation fluctuations not explained by other structural shocks."[16] In this analysis, we deliberately avoid placing prior identification restrictions on inflation expectation shocks, instead adopting an "ex-post" evaluation approach to confirm the nature of these shocks by examining estimated impulse response functions and the developments in identified structural shocks.[17]

Furthermore, in TVP-VAR, since reduced-form parameters vary each period, we must verify whether identified shocks satisfy sign restrictions in each period. For structural shock identification, given θ_t for each period, we sample 100 transformation matrices Ξ_t that satisfy the sign restrictions used for identification, then select the matrix that minimizes the total distance of each matrix element from its median value.[18,19]

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[16] The approach of not imposing restrictions on the most crucial shock appears in previous research. For example, Weale and Wieladek (2016), analyzing the impact of central bank large-scale asset purchases on the real economy, deliberately avoid imposing restrictions on how asset purchase amounts affect CPI and GDP, instead diagnostically (agnostically) analyzing effects by examining impulse response shapes.

[17] In contrast, Neri (2023) imposes a priori sign restrictions on inflation expectation shocks.

[18] More specifically, the procedure is as follows: First, randomly sample 100 matrices satisfying sign restrictions (A_1, A_2, …, A_{100}). Then, calculating the median of each element ($\bar{a}_{ij}$), where $a_{ij,k}$ represents element (i, j) of matrix k. Based on these, calculate statistic $d_k = \sum_{i=1}^{4}\sum_{j=1}^{4}(a_{ij,k} - \bar{a}_{ij})^2$ for each matrix and adopt the matrix minimizing d_k.

[19] Another possible approach would be to uniquely identify Ξ satisfying sign restrictions throughout the estimation period and use these for shock identification, but this is not employed in this paper due to

4. Estimation Results

This section presents the estimation results obtained using TVP-VAR. Sections 4.1 and 4.2 examine the relationship between long-term inflation expectations, economic activity, and prices. Section 4.3 discusses some factors influencing inflation expectation shocks. Section 4.4 provides a historical decomposition of inflation rates, examining the impact of long-term inflation expectations on price fluctuations over the past 25 years.

4.1. Effects of inflation expectation shocks: comparison of Japan and the U.S.

This section examines the nature of inflation expectation shocks through a comparison of impulse response functions obtained from Japanese and U.S. estimations.

Figure 2 shows the impulse response functions of three endogenous variables (excluding long-term inflation expectations) to a positive one-standard-deviation inflation expectation shock in both countries.[20] Since we estimate a time-varying parameter model that allows for temporal changes in variable relationships, these impulse responses represent averages over the estimation period. The results reveal contrasting responses to inflation expectation shocks between the two countries.

Examining shadow rate responses to shocks that raise long-term inflation expectations, we observe statistically significant increases in the U.S., while Japan shows responses of the same sign but without statistical significance. This can be interpreted as policy responses aimed at stabilizing inflation expectations in the U.S., where long-term inflation expectations are generally anchored to the inflation target. Conversely, in Japan, which has experienced deflation and low inflation, monetary policy has attempted to support economic activity and prices by maintaining policy rates at low levels, suggesting a tendency to avoid monetary tightening that would suppress shocks raising long-term inflation expectations. This impulse response function can be interpreted as reflecting these tendencies. Conversely, when shocks lowering long-term inflation expectations occurred, such as during the deflationary period of the 2000s, the response may reflect constraints on sufficient policy responses—specifically, aggressive monetary easing—due to the ELB constraint.

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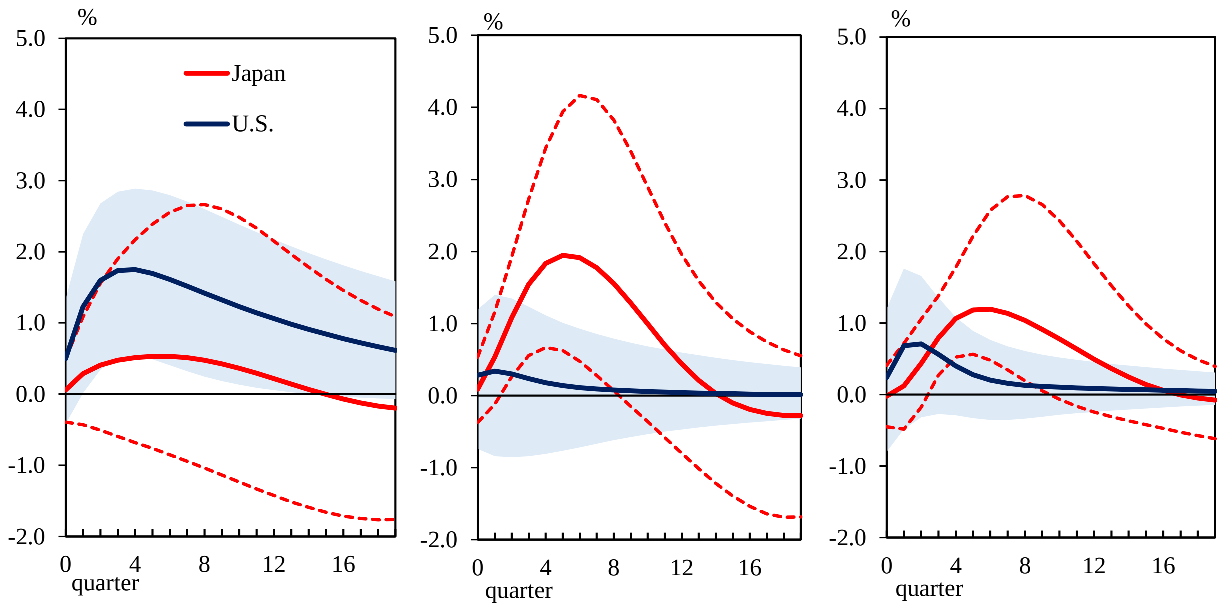
extreme computational burden.

[20] For simplification, we show average impulse responses over the estimation period. Impulse responses for other shocks and variables not shown here are presented in Appendix B.

Figure 2: Impulse response functions to inflation expectation shocks

(a) Shadow rate (b) Output gap (c) Inflation rate



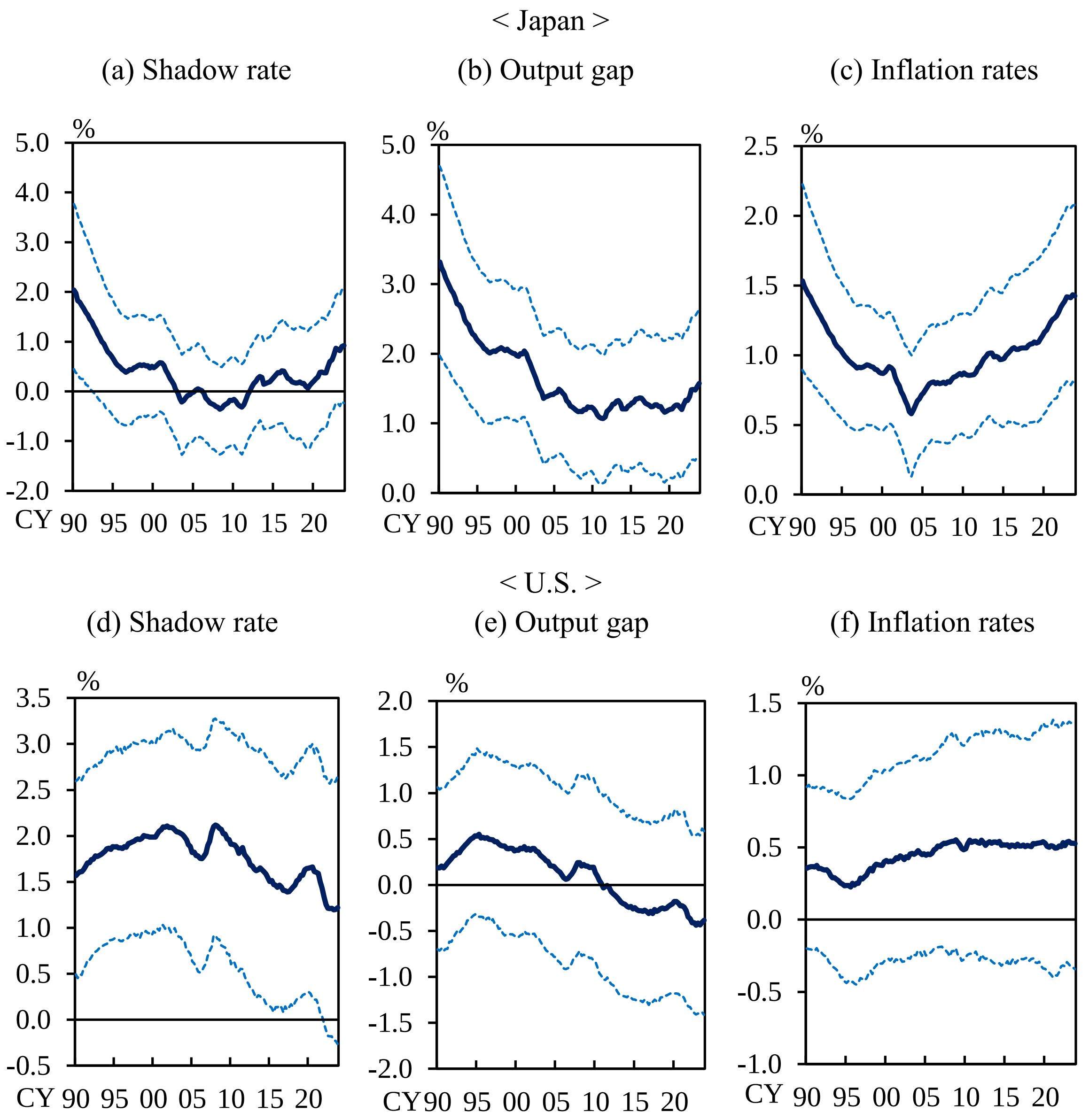
Note: The solid lines indicate median responses while shaded areas represent the 16th-84th percentile range. The shock occurs at period 0. Responses show the average dynamics over the estimation period following a one-standard-deviation shock to inflation expectations (Japan: 0.26%, U.S.: 1.0%).

Regarding the impact of inflation expectation shocks on the output gap and inflation rate, in Japan, shocks that raise long-term inflation expectations cause statistically significant increases in the output gap, which can be interpreted as an economic stimulus effect through lowering real interest rates. Furthermore, positive inflation expectation shocks significantly raise inflation rates, consistent with Phillips curve predictions.

In contrast, in the U.S., inflation expectation shocks do not have statistically significant effects on either the output gap or inflation rate. Considering this alongside the significant shadow rate response to inflation expectation shocks—indicating policy responses aimed at containing changes in long-term inflation expectations—, one possible interpretation is that even when shocks affecting inflation expectations occur, U.S. economic agents anticipate central bank policy responses to suppress them, leading to self-fulfilling limited impact on production and prices.[21]

[21] From the mid-1980s to 2007, U.S. inflation rates remained stable, a period known as the Great Moderation. Two major explanations exist for this phenomenon: the Good Luck hypothesis, suggesting the absence of major economic shocks during this period (Stock and Watson, 2003, etc.), and the Good Policy hypothesis, attributing it to improved monetary policy effectiveness (Bernanke, 2004, etc.). In this context, the results of our analysis can be seen as supporting the Good Policy hypothesis in that high credibility in the U.S. monetary policy contributed to inflation stability.

Figure 3: Time-varying patterns of impulse responses
to inflation expectation shocks (four quarters after the shock)



Note: The figures show the responses of each variable four quarters after the shock at each estimation point. Solid lines represent median responses, and bands shows the 16th-84th percentile range. The shock sizes are normalized to a one-standard-deviation increase in inflation expectations for both Japan and the U.S. (Japan: 0.26%, U.S.: 1.0%.)

Figure 3, showing temporal changes in impulse response function (four quarters after the shock) reveals that in Japan, the impact of inflation expectation shocks on shadow rates, output gaps, and inflation rates diminished through the early 2000s. The statistical significance patterns for both Japan and the U.S. remain largely consistent with those shown in Figure 2 (estimation period averages). Additionally, the impact of Japanese inflation expectation shocks on inflation rates has increased since the 2010s, suggesting that the "price stability target" and QQE in 2013 may have influenced the transmission effects of inflation expectations.

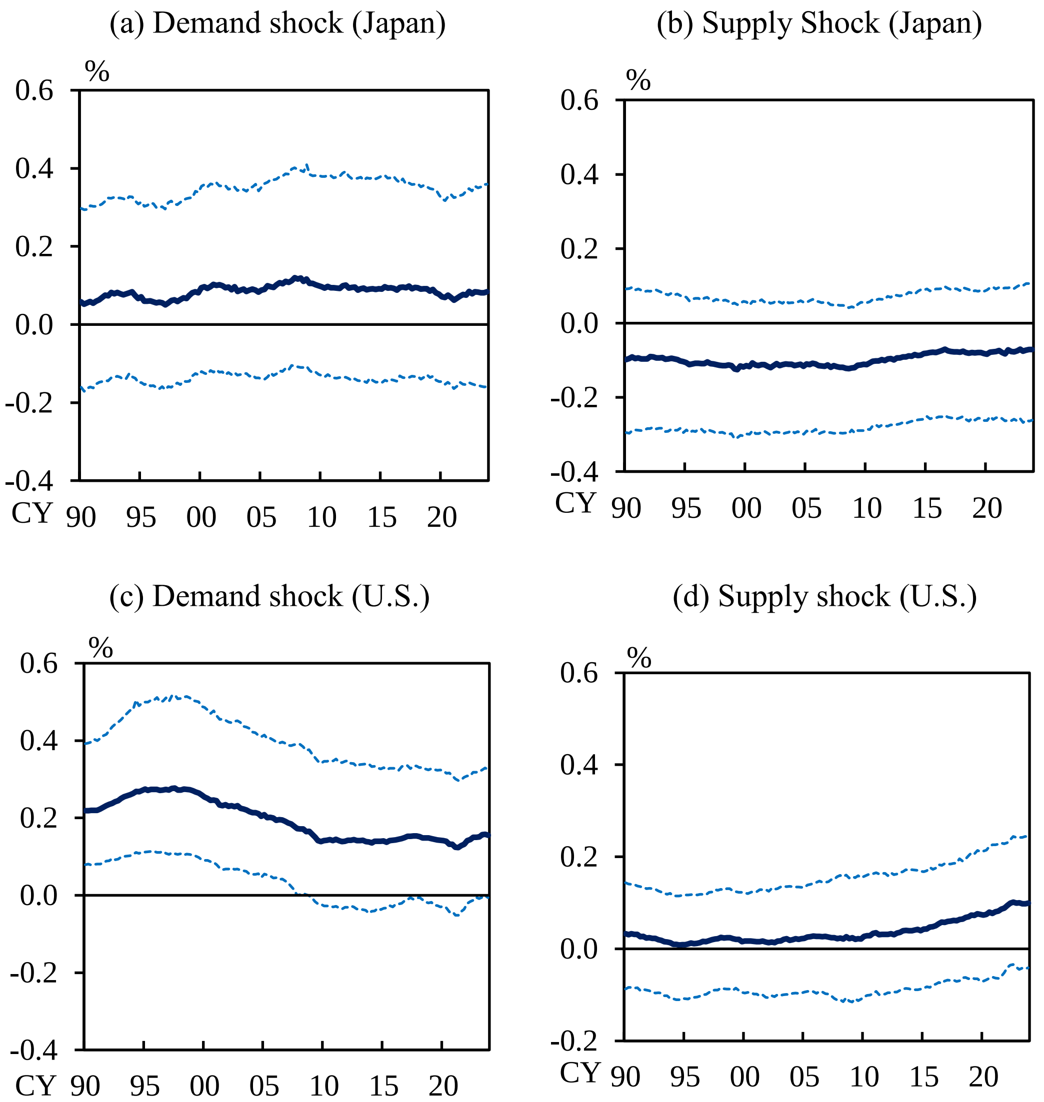
4.2. Relationship between inflation expectations and demand/supply shocks

This section examines temporal changes in the relationship between inflation expectations and real economic activity. Specifically, by analyzing temporal changes in impulse response functions as in the previous section, we examine how long-term inflation expectations in Japan and the U.S. responded to demand and supply shocks, and how these responses have evolved over time.

Figures 4(a) and (b) show impulse response functions (four quarters after the shock) of Japanese long-term inflation expectations to demand and supply shocks. The results indicate that long-term inflation expectations are relatively insensitive to both shocks, with this relationship remaining largely unchanged throughout the estimation period. This suggests that Japanese long-term inflation expectations primarily fluctuate due to idiosyncratic factors rather than demand or supply shocks.

Examining the U.S. long-term inflation expectations' impulse response functions (four quarters after the shock) in Figures 4(c) and (d), we observe that while responses to supply shocks show no statistical significance (similar to Japan), responses to demand shocks present a different pattern. Particularly in the first half of the estimation period, inflation expectations showed statistically significant responses to demand shocks. However, the magnitude of these responses gradually decreased, becoming statistically insignificant in the latter half of the estimation period. These results suggest that the U.S. long-term inflation expectations have become less responsive to exogenous shocks affecting macro-level demand and supply factors since around the 2010s.

Figure 4: Impulse response function of long-term inflation expectations to demand and supply shocks



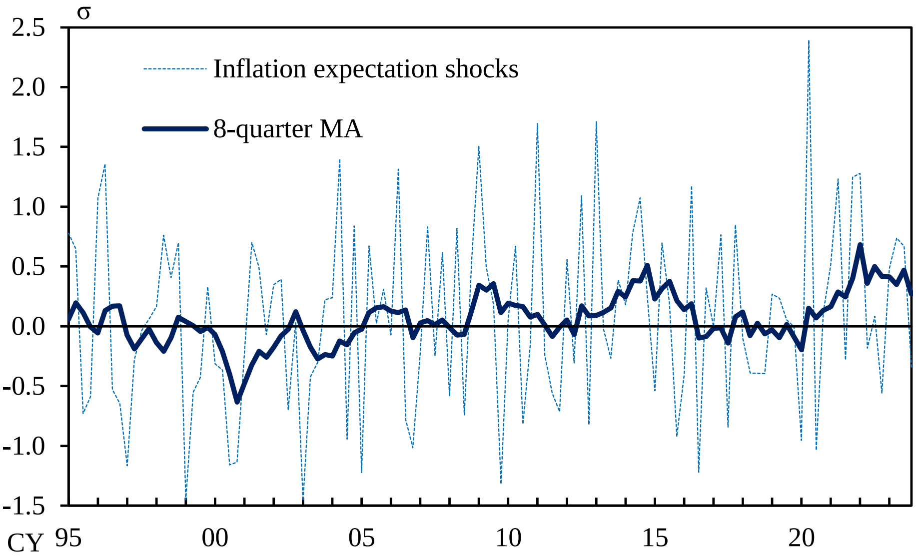
Note: The figures shows the responses of inflation expectations four quarters after each shock at each estimation period. Solid lines represent median responses, and bands show the 16th-84th percentile range. Both demand and supply shocks are normalized to generate a 1 percent increase in inflation rate.

4.3. Developments in inflation expectation shocks

The structural shock identification methodology employed in this paper does not impose explicit restrictions on inflation expectation shocks. Therefore, in addition to confirming impulse response functions, it is analytically important to examine whether the time series of identified structural shocks yields interpretable results.

The evolution of inflation expectation shocks appears to capture several characteristic features of the Japanese economy (Figure 5). First, during the period from the late 1990s

Figure 5: Development of inflation expectation shocks



Note: Structural shocks are normalized after adjusting for time-varying volatility.

through the 2000s, when deflation was a significant concern in the Japanese economy, shocks continuously suppressing inflation expectations occurred. Second, for some time following the introduction of the "price stability target" and QQE in 2013, shocks raising inflation expectations emerged. Third, during the post-COVID-19 price increase phase from 2021 onward, positive inflation expectation shocks occurred.

The next point of interest is determining to what extent the identified inflation expectation shocks are attributable to central bank policy responses, such as the introduction of the "price stability target." Since this paper uses a small-scale model with only four variables, the identified inflation expectation shocks may include effects from variables not included in the model. To examine this issue, Neri (2023) conducted regression analysis using inflation expectation shocks as the dependent variable, and variables that could influence inflation expectations (such as oil prices) as explanatory variables, after identifying structural shocks using a four-variable VAR similar to this paper.

Following Neri (2023), this section conducts regression analysis using inflation expectation shocks as the dependent variable, and multiple variables identified in previous research as potentially influencing inflation expectations as explanatory variables. The explanatory variables include: (1) oil price shocks, (2) U.S. inflation expectation shocks, and (3) USD/JPY exchange rates. Aastveit et al. (2023) exemplified research suggesting that oil price dynamics can influence inflation expectation formation. Using a structural VAR model, they reported that oil price dynamics affect both realized inflation rates and inflation expectations dynamics. For exogenous oil price shocks, we use the oil price surprise series estimated in Baumeister (2023).[22] The inclusion of U.S. inflation expectation shocks as an explanatory variable considers the observation that foreign-originated shocks are important determinants of Japanese price dynamics and inflation expectations, as discussed in Fukunaga et al. (2024a). Additionally, Ciccarelli and Garcia (2015) discussed international correlation in medium to long-term inflation expectations. We account for U.S.-originated shocks by using inflation expectation shocks derived from U.S. TVP-VAR estimations as explanatory variables. Similarly, foreign economic conditions may influence inflation expectation formation through exchange rate channels, hence we include quarter-on-quarter changes in USD/JPY rates as an explanatory variable.

Table 2 presents the estimation results. Single regression analyses of the three variables reveal that only U.S. inflation expectation shocks show statistically significant effects (p-value = 0.06). Oil price shocks and USD/JPY rate fluctuations show no statistically significant relationships. These results suggest that inflation expectation shocks identified in Japan's TVP-VAR model may incorporate effects of foreign-originated shocks not captured by other structural shocks. U.S. inflation expectation shocks likely reflect both U.S.-specific factors (such as U.S. price trends and monetary policy stance) and global price fluctuation factors like international commodity markets, suggesting these complex factors may directly and indirectly influence the Japanese economy.

Estimation equation (4) shows results using oil price shocks, U.S. inflation expectation shocks, and USD/JPY rate fluctuations as explanatory variables. The adjusted R-squared of 0.128 indicates low explanatory power of these three variables for identified idiosyncratic shocks. Figure 6 shows decomposition of Japanese inflation expectation shocks given equation (4)'s coefficients, with most shocks explained by estimation residuals. This suggests that identified inflation expectation shocks are not strongly influenced by these variables (oil prices, global factors, exchange rate fluctuations). Considering the occurrence of inflation expectation-raising shocks for some time following the introduction of the "price stability target" and QQE, such policy factors may be interpreted as being identified as part of inflation expectation shocks.

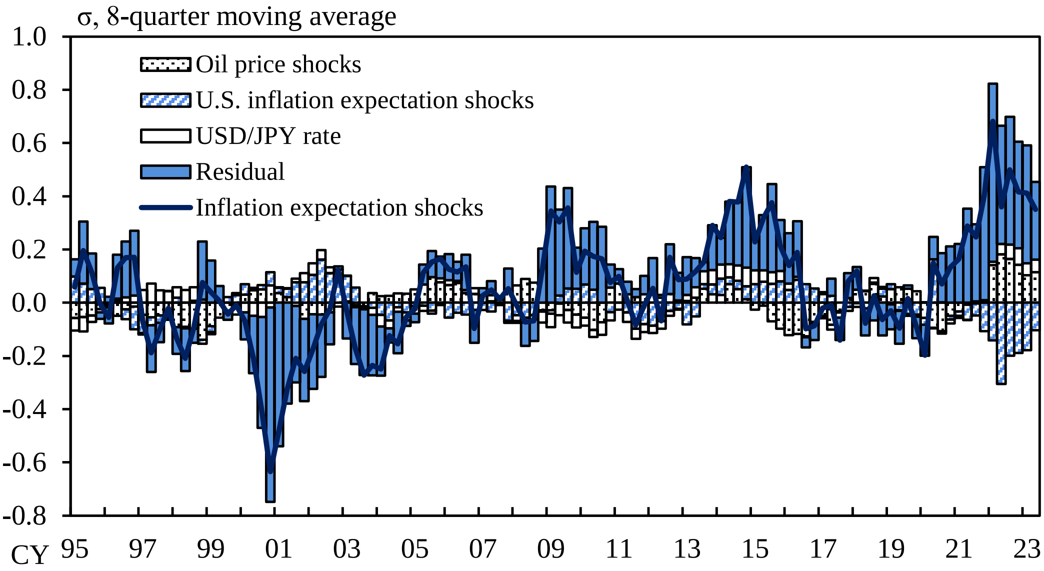
[22] Shock data are available from the author's website (https://sites.google.com/site/cjsbaumeister/datasets).

Table 2: Regression results – inflation expectation shocks

Dependent variable： Inflation expectation shocks				
Explanatory variables	(1)	(2)	(3)	(4)
Oil price shocks	2.19 (1.38)	-	-	2.95** (1.41)
U.S. Inflation expectation shocks	-	1.26** (0.53)	-	1.46*** (0.54)
USD/JPY rate (q/q % chg.)	-	-	2.83 (1.93)	1.67 (2.20)
Adj. R-square	0.022	0.075	0.010	0.128
Estimation period	2000/Q1～2023/Q2			

Note: Numbers in parentheses are Huber-White standard errors. *** and ** denote statistical significance at the 1% and 5% levels.

Figure 6: Decomposition of inflation expectation shocks

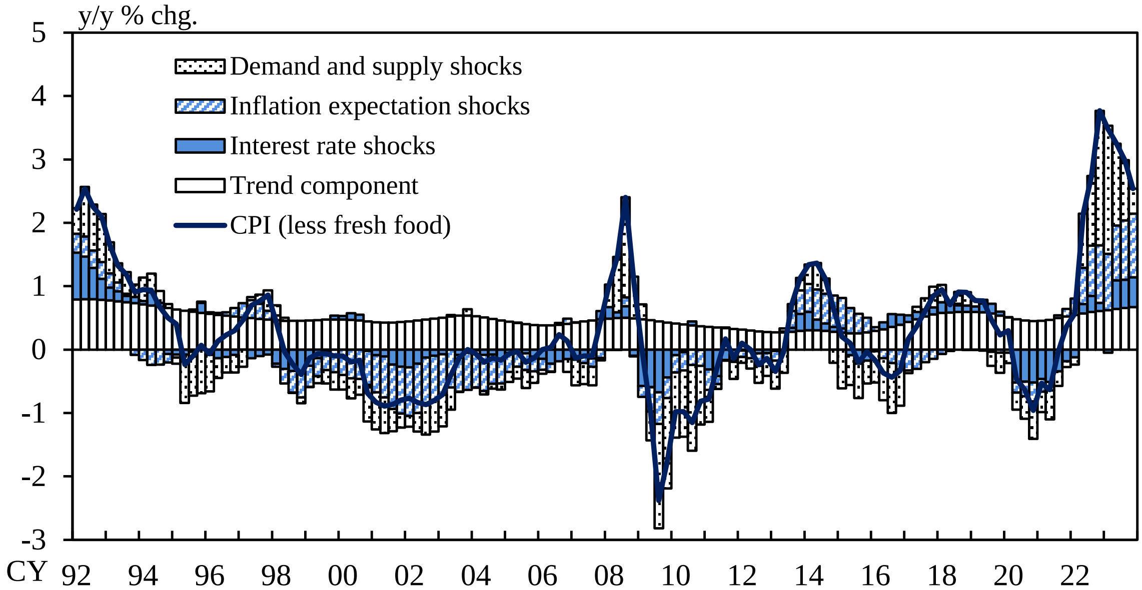


Note: Values represent 8-quarter moving averages.

4.4. Historical decomposition of inflation rate

While impulse response functions are useful tools for analyzing average responses of endogenous variables to structural shocks, they cannot analyze the relative importance of each shock during specific episodes or periods. Therefore, this section performs historical decomposition to examine the extent to which shocks specific to long-term inflation

Figure 7: Historical decomposition of inflation rate



Sources: Bank of Japan; Bloomberg; Consensus Economics inc.,"Consensus Forecasts"; QUICK, "QUICK Monthly Market Survey <Bonds>."

expectations influenced price fluctuations during each period.[23]

The historical decomposition of inflation rates suggests that changes in long-term inflation expectations have been an important factor influencing price fluctuations in Japan since 1990 (Figure 7). Examining specific phases reveals that from the late 1990s, inflation expectation shocks exerted additional downward pressure on inflation rates beyond negative demand and supply shocks. This suggests that during this period, inflation expectations declined more than what would be expected from real economic conditions, collectively generating deflationary pressure. Focusing on the period following the introduction of the "price stability target" of 2% and QQE in 2013, while the rise in long-term inflation expectations during this period contributed to some extent to increasing inflation rates, it was not sufficiently effective to immediately anchor inflation at 2%. Nevertheless, it may have had some effect in terms of reversing the situation from the late 1990s to early 2000s where negative inflation expectation shocks persistently suppressed inflation rates.

Since the 2020s, factors specific to long-term inflation expectations have also been pushing up prices, against a backdrop of rising import prices and tight labor market conditions. However, determining whether these effects are sustainable will require the accumulation of additional data.

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[23] For the concept of historical decomposition in nonlinear VARs, including TVP-VAR, refer to Wong (2017). In this paper, we refer to the "steady state component" in Wong (2017) as the trend component.

5. Concluding Remarks

This paper analyzed the impact of shifts in long-term inflation expectations on economic activity and price dynamics. Our findings confirm that in Japan, exogenous shocks that raise long-term inflation expectations improve the output gap and generate upward pressure on inflation rates. This suggests that increased inflation expectations produced economic stimulus effects through lowering real interest rates.

Examining specific periods, during the late 1990s, negative shocks to long-term inflation expectations functioned as factors persistently suppressing prices, in addition to negative demand and supply factors, suggesting that declining long-term inflation expectations generated deflationary pressure. Subsequently, following the introduction of the "price stability target" of 2% and QQE in 2013, long-term inflation expectations reversed course to contribute as factors pushing up inflation rates, becoming an important factor in moving the Japanese economy away from deflation. These results suggest that the introduction of the "price stability target" and QQE in 2013 may have had some effect in transforming long-term inflation expectations. However, as realized inflation rates subsequently declined due to factors such as falling oil prices, the temporarily elevated long-term inflation expectations decreased, failing to anchor inflation expectations to the "price stability target" of 2%.

Two future research directions warrant consideration. First, while our analysis confirmed that increases in long-term inflation expectations had certain economic stimulus effects in Japan, there remains room for additional analysis regarding detailed transmission mechanisms—for example, the relationship with consumption and investment. Second, further analysis is needed regarding the extent to which central banks can influence private sector expectations. In particular, the effect that central banks can have on expectation formation may well differ between situations where policy rates are subject to ELB and those where they are not. These issues, along with elucidating inflation expectation formation mechanisms, remain important areas for future research.

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Appendix A. Details of Estimation Algorithm

This section details the algorithm used for TVP-VAR estimation. The description and algorithm largely draw from Benati and Mumtaz (2007), and Blake and Mumtaz (2017).

The model structure is as follows:

$$Y_t = B_{0,t} + B_{1,t}Y_{t-1} + \cdots + B_{p,t}Y_{t-p} + u_t \equiv X'_t\ \theta_t + u_t$$

$$Var(u_t) = A_t^{-1}\Omega_t(A_t^{-1})'$$

$$A_t \equiv \begin{bmatrix} 1 & 0 & 0 & 0 \\ \alpha_{21,t} & 1 & 0 & 0 \\ \alpha_{31,t} & \alpha_{32,t} & 1 & 0 \\ \alpha_{41,t} & \alpha_{42,t} & \alpha_{43,t} & 1 \end{bmatrix}, \Omega_t \equiv \begin{bmatrix} \sigma_{1,t} & 0 & 0 & 0 \\ 0 & \sigma_{2,t} & 0 & 0 \\ 0 & 0 & \sigma_{3,t} & 0 \\ 0 & 0 & 0 & \sigma_{4,t} \end{bmatrix}$$

where θ_t, $\alpha_{ij,t}$, and $\ln(\sigma_{i,t})$ follow random walk processes:

$$\theta_t = \theta_{t-1} + \nu_t$$

$$\alpha_{ij,t} = \alpha_{ij,t-1} + \zeta_{ij,t}$$

$$ln(\sigma_{i,t}) = ln(\sigma_{i,t-1}) + \eta_{i,t}$$

ν_t, $\zeta_{ij,t}$, and $\eta_{i,t}$ follow normal distributions with zero mean and variances Q, S_{ij}, and w_i respectively. Based on these assumptions, the estimation proceeds as follows:

Step 1: Setting prior distributions and initial values

First, set parameter prior distributions and initial values. Using the first 40 quarters ($T_0 = 40$) as training data (Y_0) to create reference points, estimate a fixed-parameter VAR model. With $X_{0,t} = [1, Y_{0,t-1}, \dots, Y_{0,t-p}]$, VAR parameters ($\beta_0$) are estimated using OLS:

$$\beta_0 = \left(X'_{0,t}X_{0,t}\right)^{-1}(X'_{0,t}Y_{0,\mathrm{t}})$$

Defining Σ_0 as follows:

$$\Sigma_0 = \frac{(Y_{0,t} - X_{0,t}\beta_0)'(Y_{0,t} - X_{0,t}\beta_0)}{T_0}$$

Then, the coefficient variance-covariance matrix ($p_{0|0}$) is:

$$p_{0|0} = \Sigma_0 \otimes \left(X'_{0,t}X_{0,t}\right)^{-1}$$

Given these, first set prior distribution of Q (governing parameter time variation) as the inverse Wishart distribution ($p(Q) \sim IW(Q_0, T_0)$), where $Q_0 = p_{0|0} \times T_0 \times \tau$ with $\tau =$

3.5e-4 following previous research. Initial values and variances for state variable β_t are set to β_0 and $p_{0|0}$, respectively.

Next, set prior distribution of S (variance of A_t determining TVP-VAR residual covariance) as the inverse Wishart distribution ($p(S) \sim IW(10^{-3}, T_0)$). Initialize A_t using the normalized Cholesky decomposition of Σ_0, with corresponding lower triangular components. Initial variance is set to $\mathrm{abs}(A_t) * 10$ based on Benati and Mumtaz (2007).

For $i = 1, \ldots, 4$, set initial values of $\sigma_{i,t}$ to squared VAR residuals from training data. Means of prior distribution are set to squared diagonal components of Σ_0, with variance of 10.

<u>Step 2: Sample w_i</u>

Given σ_i, draw samples of w_i from inverse gamma distribution for each variable i (i = 1, ..., 4).

<u>Step 3: Sample Ω_t</u>

Given w_i, draw samples of Ω_t using the Metropolis-Hastings method proposed by Jacquier et al. (1994).

<u>Step 4: Sample A_t</u>

Given β_i, Ω_t, and S, draw samples of A_t using the simulation smoother proposed by Carter and Kohn (1994).

<u>Step 5: Sample S</u>

Given A_t, draw samples of S from the inverse Wishart distribution.

<u>Step 6: Sample β_{t}t</u>

Given A_t, Ω_{t}, and Q, draw samples of β_t using the Carter and Kohn (1994) simulation smoother.

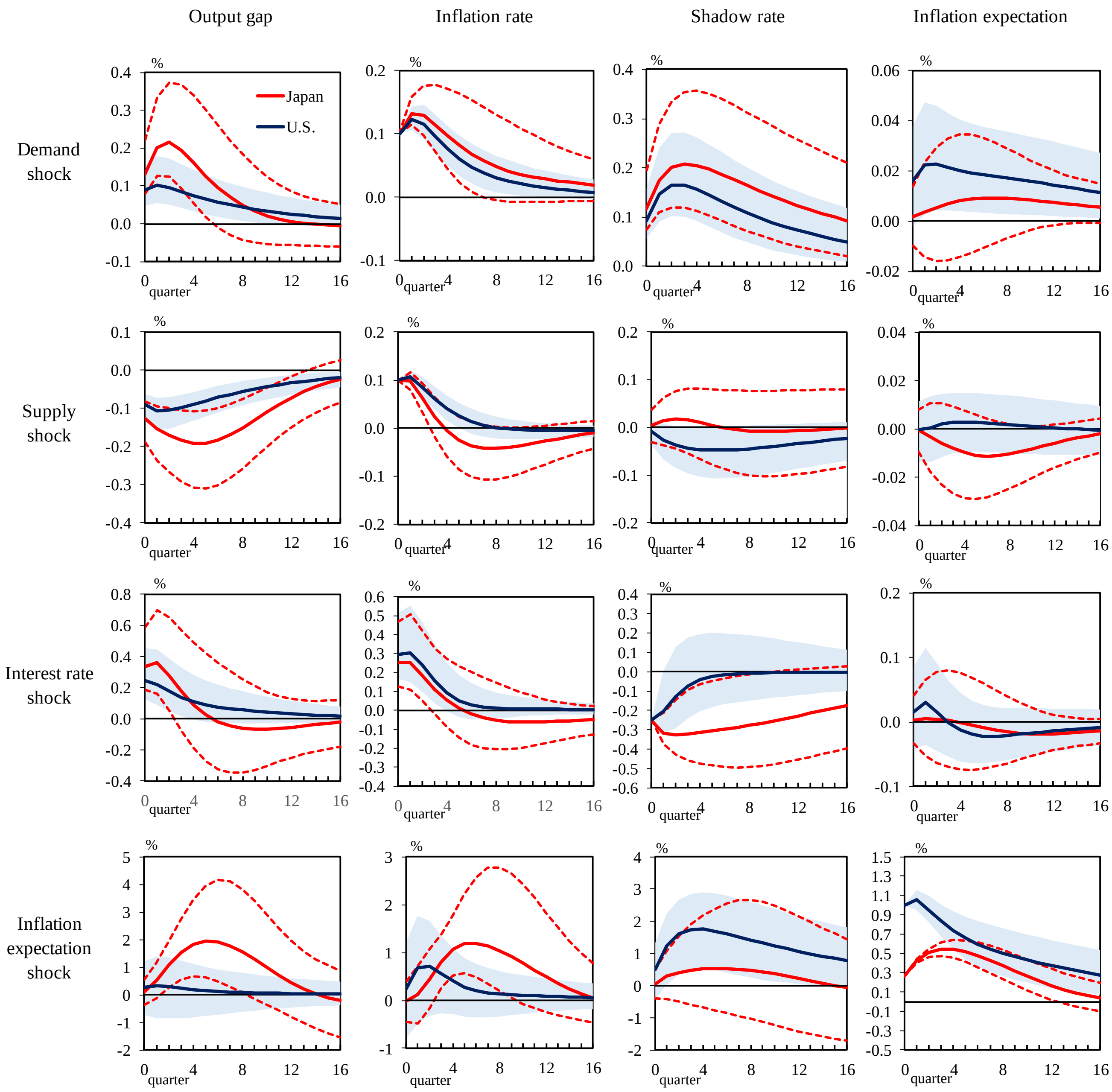
<u>Step 7: Sample Q</u>

Given β_t, draw sample of Q from the inverse Wishart distribution.

<u>Step 8: Repeat</u>

Repeat Steps 2 to 7 50,000 times, discarding the first 40,000 as the burn-in period and using the remaining 10,000 samples for coefficient estimation.

Appendix B. Impulse Response Functions to All Structural Shocks

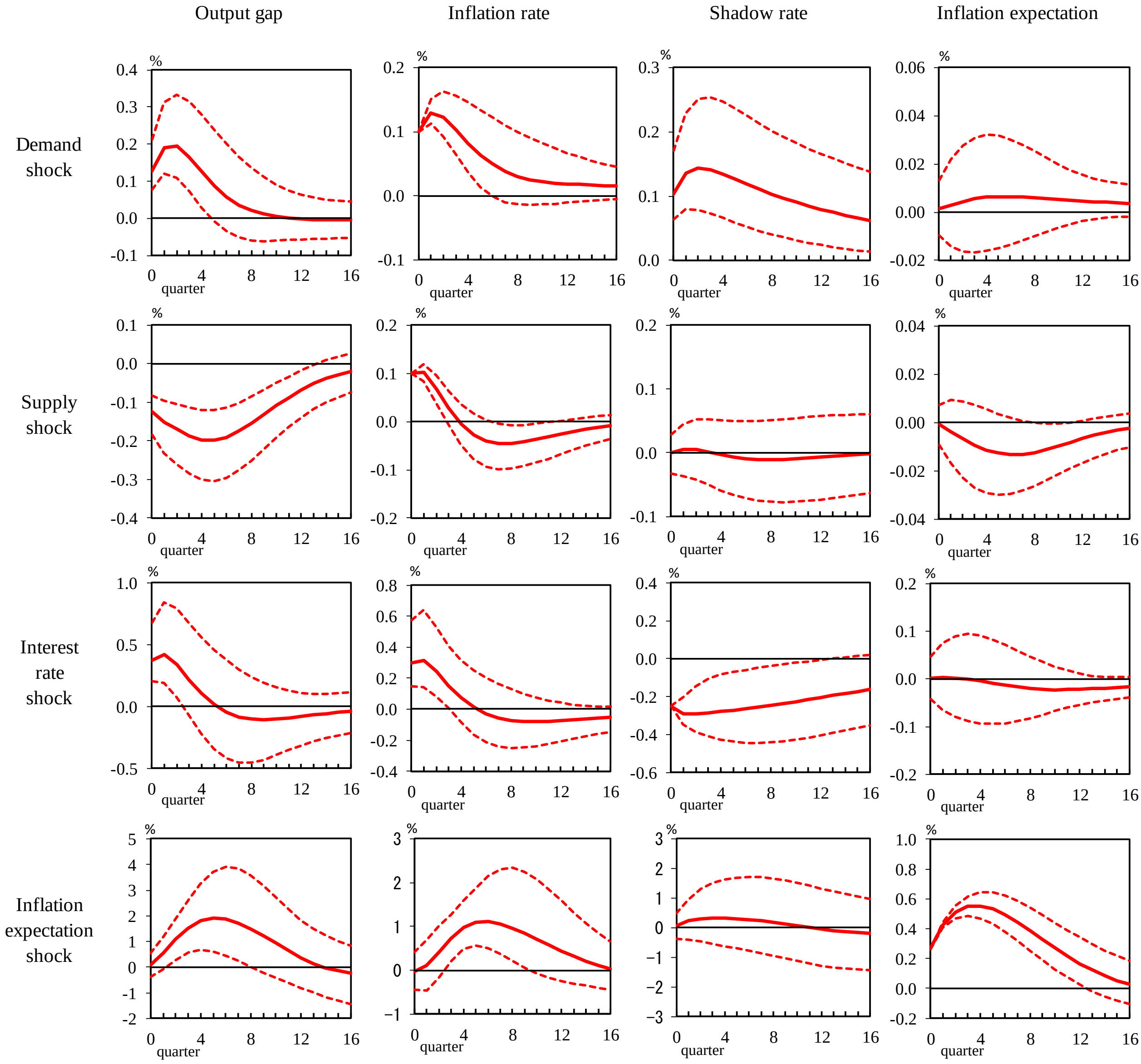


Note: The figures show average impulse responses over the estimation period. The solid lines indicate medians, while the bands show the 16th-84th percentile ranges. For demand and supply shocks, the responses show variable reactions to shocks that increase the inflation rate by 0.1%. For interest rate shocks, the responses show variable reactions to shocks that decrease the shadow rate by 25 basis points. For inflation expectation shocks, we calculate the standard deviation of inflation expectations over the estimation period and apply shocks that generate a one-standard-deviation increase in inflation expectations (approximately 0.26% for Japan and 1.0% for the U.S.).

Appendix C. Robustness Checks

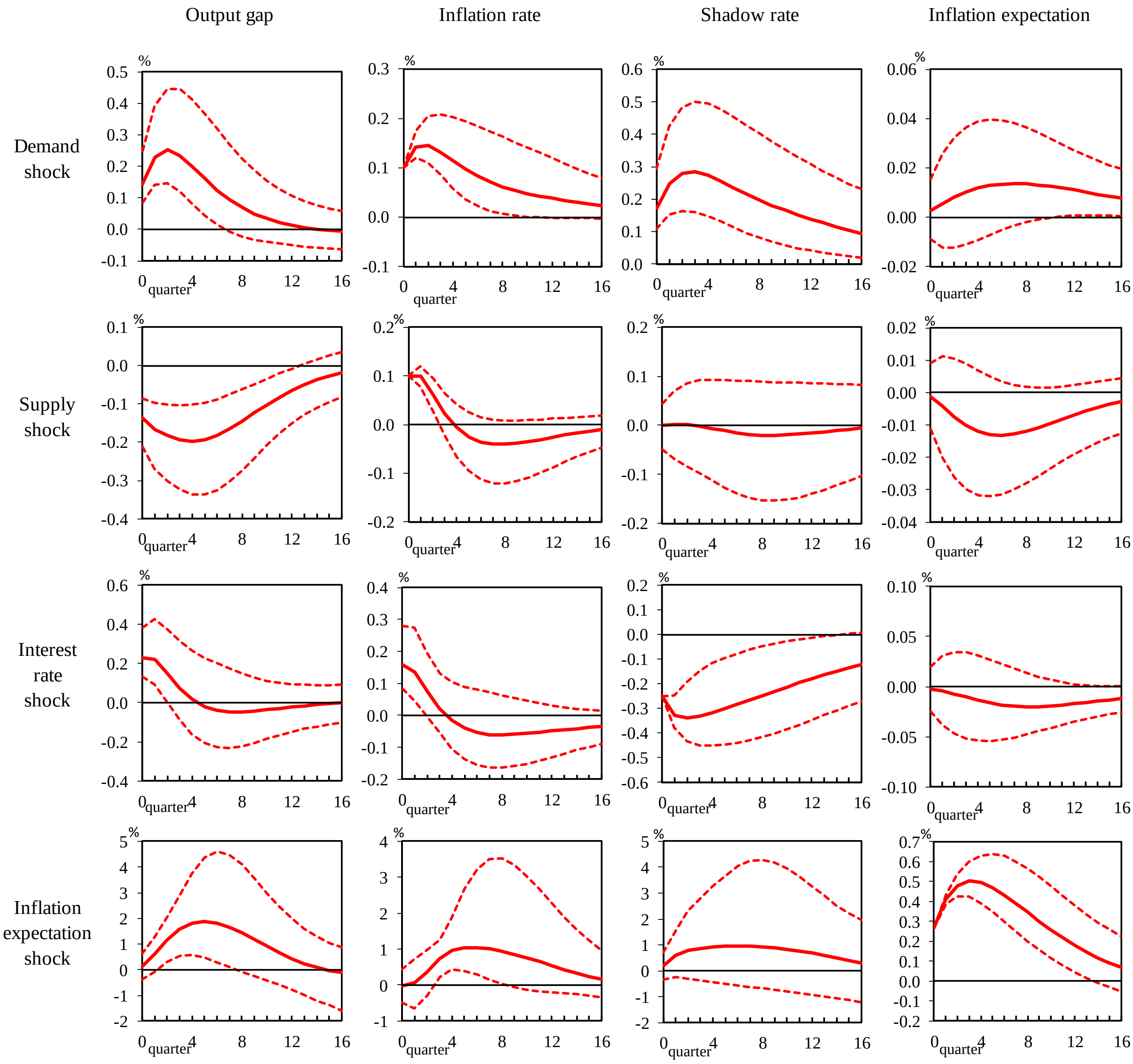
For robustness checks of the Japanese estimation results, we present impulse responses using alternative shadow rates: (1) based on Wu and Xia (2016) methodology (Figure A1), and (2) based on Imakubo and Nakajima (2015) methodology (Figure A2).

Figure A1: Impulse response functions using the shadow rate based on Wu and Xia (2016) methodology



Note: The figures show average impulse responses over the estimation period. The solid lines indicate medians, while the bands show the 16th-84th percentile ranges. For demand and supply shocks, the responses show variable reactions to shocks that increase the inflation rate by 0.1%. For interest rate shocks, the responses show variable reactions to shocks that decrease the shadow rate by 25 basis points. For inflation expectation shocks, we calculate the standard deviation of inflation expectations over the estimation period and apply shocks that generate a one-standard-deviation increase in inflation expectations (approximately 0.26%).

Figure A2: Impulse response functions using the shadow rate based on Imakubo and Nakajima (2015) methodology

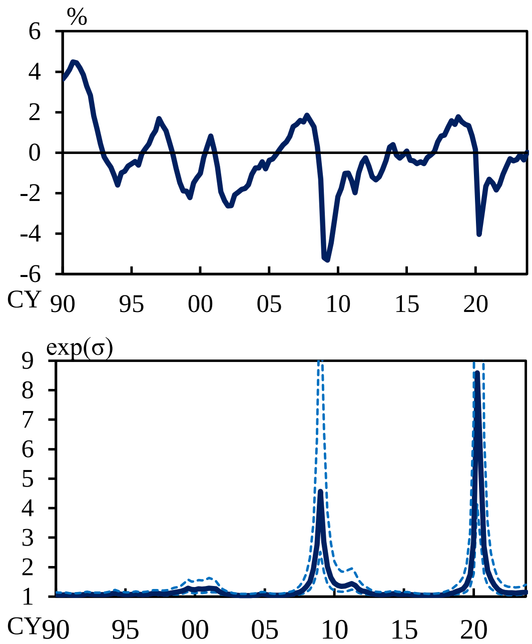


Note: The figures show average impulse responses over the estimation period. The solid lines indicate medians, while the bands show the 16th-84th percentile ranges. For demand and supply shocks, the responses show variable reactions to shocks that increase the inflation rate by 0.1%. For interest rate shocks, the responses show variable reactions to shocks that decrease the shadow rate by 25 basis points. For inflation expectation shocks, we calculate the standard deviation of inflation expectations over the estimation period and apply shocks that generate a one-standard-deviation increase in inflation expectations (approximately 0.26%).

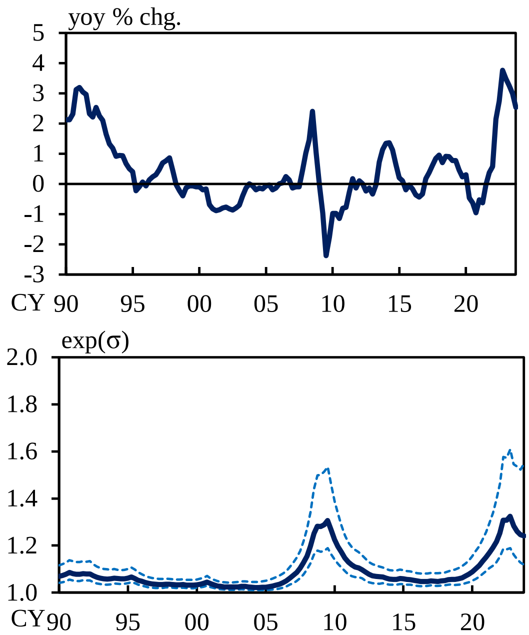
Appendix D. Data and Estimated Time-varying Volatility

Figure A3: Variables (top panels) and estimated time-varying volatility (bottom panels)

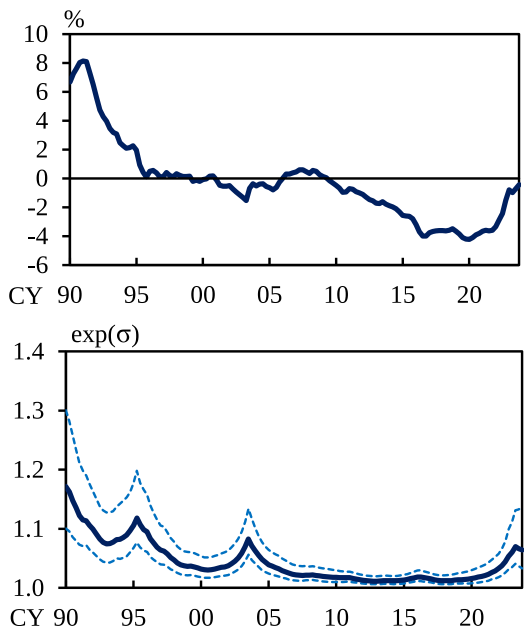
(a) Output gap



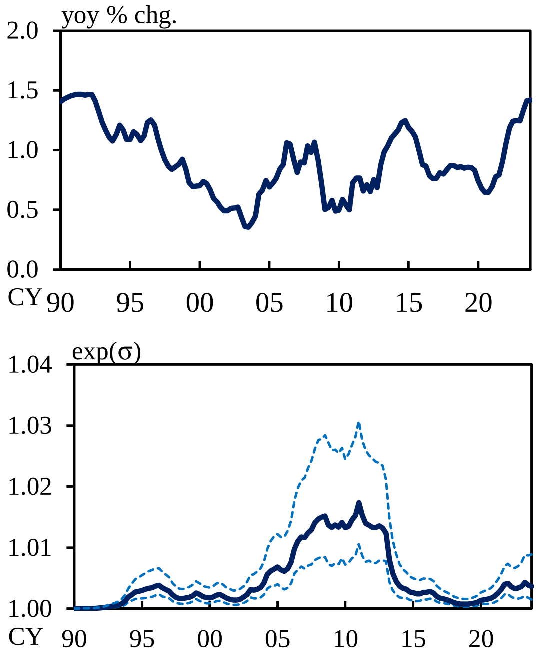
(b) Inflation rate



(c) Shadow rate



(d) Inflation expectations



Note: For time-varying volatility, solid lines represent median values, and dotted lines show the 16th-84th percentile range.

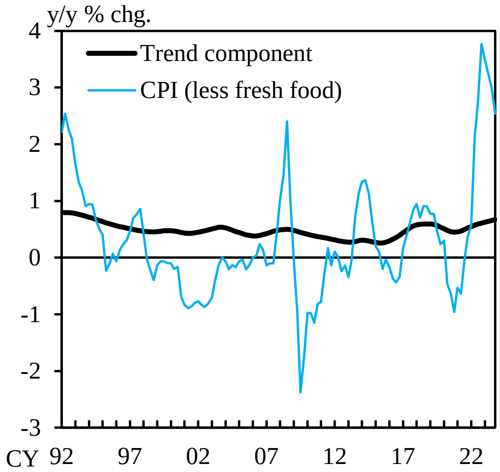
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Hirata et al. (2024); Osada and Nakazawa (2024)

Appendix E. Trend Components of Inflation Rate and Shadow Rate

In TVP-VAR, steady-state values—the levels of endogenous variables that would prevail in the absence of structural shocks—also vary. Using this property, we can estimate the trend components of inflation rates and shadow rates at each point in time. These results are shown in Figure A4.

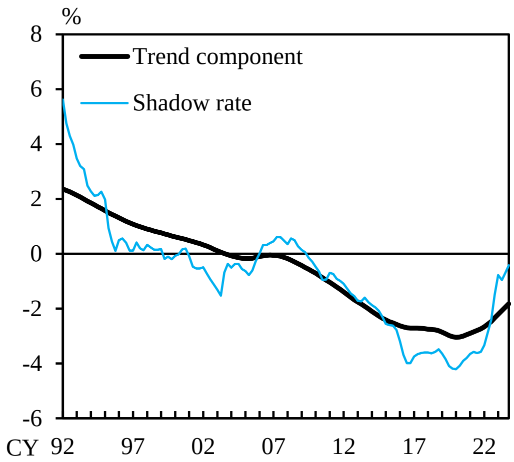
Figure A4: Trend components

(a) Inflation rate



Source: Ministry of Internal Affairs and Communications

(b) Shadow rate



Source: Hirata et al.(2024)

The results indicate that the steady-state inflation rate has shown a gradual upward trend since bottoming out in 2014. Additionally, examining the steady-state shadow rate reveals a gradual declining trend, which likely corresponds to the decline in Japan's natural rate of interest during this period.