Discussion Paper Series

RIEB

Kobe University

DP2023-04

Inflation, Business Cycle, and Monetary Policy: The Role of Inflationary Pressure

Masahiko SHIBAMOTO

March 2, 2023

Research Institute for Economics and Business Administration

Kobe University

2-1 Rokkodai, Nada, Kobe 657-8501 JAPAN

Inflation, Business Cycle, and Monetary Policy: The Role of Inflationary Pressure*

Masahiko Shibamoto†

March 2, 2023

Abstract

A novel empirical framework is proposed to analyze the causal relationships among future inflation, the business cycle, and monetary policy. It measures inflationary pressures as anticipated shocks to future inflation caused by changes in some predictors of inflation in the structural vector autoregressive model. Empirical results reveal that identified inflationary pressures represent demand-pull factors in inflation dynamics and act as driving forces for stochastic changes in trend inflation. Furthermore, the economic significance of inflationary pressures hinges on the systematic monetary policy responses to them. The results indicate that proactive policy reactions to inflation forecasts are crucial for achieving macroeconomic stability.

JEL Classification: C32; E31; E32; E52; E58.

Keywords: Inflationary pressure; Business cycle; Monetary policy; Vector autoregressive model; Anticipated shock.

*I extend my special thanks to Kenneth N. Kuttner for his extensive help and encouragement in the writing of this paper. I am grateful to Ryuzo Miyao and the seminar participants at Kobe University for their helpful comments and discussions. I would also like to thank Azusa Komoda for providing excellent research assistance. This study received financial support from the Japan Society for the Promotion of Science (JSPS KAKENHI Grant Number 17K03804, 20H05633, and 21K01579).

†Correspondence to: Masahiko Shibamoto, Research Institute for Economics and Business Administration (RIEB) and Center for Computational Social Science (CCSS), Kobe University, 2–1, Rokkodai, Nada, Kobe, 657–8501, Japan. E–mail: shibamoto@rieb.kobe-u.ac.jp.

1 Introduction

The economic literature has pointed out that the stability of inflation and its expectations over the medium-to-long term is indispensable for sustainable economic growth. Theoretical studies, including Svensson (1997), argue that inflation forecast targeting as a framework for monetary policy can stabilize the macroeconomy. In the literature on economic history, Shibamoto and Shizume (2014) provide historical evidence that inflation expectations played a pivotal role in recovering from the Great Depression in the 1930s.[1] Recent empirical studies, including Simon et al. (2013), Blanchard et al. (2015), Hooper et al. (2020), and Hazell et al. (forthcoming), also emphasize the importance of inflation expectations being well anchored by monetary policymakers to achieve the goal of macroeconomic stability.

In practice, there is a growing consensus among policymakers that managing future inflation and inflation expectations is essential for macroeconomic stability. Under the presence of inflation inertia due to sticky information (Mankiw and Reis, 2002) and rational inattention (Sims, 2003), policymakers need to monitor not only current inflation but also the real economy and financial markets to detect future inflationary pressures. Thus, they should implement preemptive and forward-looking policies to achieve the goal of price stability.(Bernanke, 2007) Specifically, in recent years, central banks in advanced economies have been focusing on conducting monetary policy to manage future inflation, including communication with markets and forward guidance, to avoid macroeconomic fluctuations over time.

Despite the academic and practical significance of the stability of inflation expectations, the empirical evidence is still limited. In particular, the quantitative causal relationships between changes in medium-term inflation expectations, the macroeconomy, and monetary policy remain poorly understood. Indeed, a growing number of studies, such as Stock and Watson (2007), Watson (2014), and Faust and Wright (2013), highlight the significance of trend inflation and inflation expectations in inflation dynamics. However, we do not yet have a good understanding of the driving forces underlying them, partly because of the difficulty of measuring inflation expectations and the limited availability of data.

Understanding the features of the driving forces for stochastic changes in trend inflation

[1] See Shibamoto and Shizume (2014) for the literature review on the role of inflation expectations during the Great Depression and the recovery from it in the 1930s. For example, Shibamoto and Shizume (2014) provides anecdotal and quantitative evidence that Japan's recovery from the Great Depression in the 1930s involved a regime shift from deflation expectations to inflation expectations through the exchange rate policy of inducing yen depreciation.

could have significant implications for the business cycle and the conduct of monetary policy. Policy responses to inflation differ depending on whether the inflation is driven by cost-push or demand-pull factors, as these factors have different effects on the business cycle. Given the trade-off between inflation and the business cycle, it would be desirable for policymakers to make a proactive policy response to inflationary pressures associated with demand-pull factors to achieve the goal of macroeconomic stability. Consequently, the policy response to demand-pull pressures in inflation expectations, even if not reflected in the current inflation, could be more aggressive than the response to unexpected innovations in realized inflation. Furthermore, we expect that the economic significance of inflationary shocks would differ depending on the country's macroeconomic structure and the preferences of its monetary policy authorities.

Hence, this study empirically evaluates the role of inflationary pressures in macroeconomic dynamics. To this end, it proposes a novel empirical framework to measure exogenous inflationary pressures and estimate its dynamic causality to the macroeconomy. Specifically, this study constructs a vector autoregressive (VAR) model with inflation and some predictors (i.e., real output and financial variables), which can help forecast inflation. We then impose restrictions in the VAR model to identify anticipated shocks to future inflation, namely inflationary pressure shocks. Using the structural VAR model, the dynamic causal effects of inflationary pressure shocks on the macroeconomy are estimated. The empirical results are reported by applying our empirical framework to the macroeconomy in Japan and the U.S. since the early 1980s.

This study finds four significant empirical results that contribute to the extant literature. First, identified inflationary pressure shocks qualify as demand-pull factors, whereas unexpected inflationary shocks can be characterized as cost-push factors. Second, inflationary pressure shocks capture the driving forces of stochastic changes in the trend underlying inflation dynamics. Third, inflationary pressure shocks represented one of the primary sources in the business cycles in Japan's bubble economy from 1986 to 1991 and the subsequent prolonged period of economic slump. Fourth, the contribution of inflationary pressures to the business cycle is quite limited in the U.S., unlike in Japan. This finding can be explained by differences in the monetary policy responses to inflationary pressures in the U.S. and Japan.

The remainder of this paper is organized as follows. Section 2 reviews the literature relevant to this study. Section 3 describes the econometric methodology used in this study to measure unexpected inflation and inflationary pressure. Section 4 presents the empirical results by applying our empirical framework. Section 5 summarizes the conclusions. The Appendix provides detailed definitions of the variables and data sources. The Online Appendix provides additional analyses and reports the robustness check and sensitivity analysis of the empirical results for the benchmark model.

2 Related work

2.1 Estimating Phillips curve

Since the seminal work by Fisher (1926) and Phillips (1958), many empirical studies of the Phillips curve have been conducted to understand the relationship between inflation and the business cycle. The standard empirical model is a triangle model of inflation, described by Gordon (1997) and references therein, in which inflation is determined by expected inflation, economic slack measures such as the output gap and unemployment, and cost-push factors. For example, recent papers such as Simon et al. (2013), Blanchard et al. (2015), Hooper et al. (2020), Del Negro et al. (2020), Hazell et al. (forthcoming), and Shibamoto (2022) quantitatively assess the short-run trade-off relationship between inflation and the business cycle by estimating the slope for the economic slack in the Phillips curve. In contrast, this study does not explicitly analyze the short-run trade-off of the Phillips curve. Rather, it focuses on the role of inflationary pressures as a shifter of the Phillips curve and unexpected inflationary shocks as a deviation of inflation from the Phillips curve.

2.2 Measuring stochastic changes in trend inflation

Many studies have developed measures of trend inflation to enhance our understanding of inflation dynamics and the accuracy of inflation forecasts (Ascari and Sbordone, 2014; Faust and Wright, 2013). Based on the premise that inflation follows a unit root process, they have constructed empirical models using time-series techniques that explicitly consider the stochastic changes in trend inflation. For example, Stock and Watson (2007) and Watson (2014) propose a methodology in which inflation is specified by the unobserved components with stochastic volatility (UCSV) model for decomposing inflation into a stochastic trend and cyclical components with time-varying volatilities of their innovations.[2] In contrast, this study does not

[2] In addition to the UCSV model, various methods have been developed to measure trend inflation. For example, Kaihatsu and Nakajima (2018) propose a method to measure trend inflation and the time-varying slope

explicitly formulate the dynamics of trend inflation in the empirical model. Instead, it employs time-series modeling that applies a VAR model, which is robust to the existence of a stochastic trend.[3] Our empirical analysis then examines how the stochastic changes in trend inflation can be captured by inflationary shocks with economic implications identified by the structural VAR model.

2.3 Utilizing asset prices for inflation dynamics and the business cycle

Most existing studies report the usefulness of asset prices as predictors of inflation and real output. Stock and Watson (2003) review the relevant literature comprehensively and list several factors, including short-term interest rates, term spreads, dividend yields, and exchange rates as potential in-sample predictors of inflation and real output.[4] Nevertheless, the purpose of this study is neither to compare the accuracy of inflation forecasts using these financial market variables nor to propose a better measure of inflation expectations. Rather, following the findings of previous studies, this study considers modeling inflation dynamics and expected future inflation using a VAR model under the premise that real output and financial markets contain informative signals about future inflation.

Several studies have empirically analyzed the role of future inflation in the macroeconomy by measuring the proxy for inflation expectations from financial market information. For example, Hamilton (1992) and Shibamoto and Shizume (2014) measure inflation expectations from commodity futures markets and empirically analyze the causal relationship between inflation expectations and macroeconomic conditions and policies during the Great Depression and the subsequent recovery around the 1930s. Using the information reflected in break-even inflation, that is, the differences between nominal and inflation-protected security yields, Christensen et al. (2010), Christensen et al. (2012), and Christensen and Spiegel (forthcoming) examine the high-frequency reactions of long-term inflation expectations of market participants to discrete macroeconomic events, including monetary policy changes.[5] In contrast, this study proposes

of the Phillips curve using a regime-switching model. Additionally, Okimoto (2019) proposes a method using a smooth-transition model in which trend inflation is permanently regime-shifting.

[3]See Sims et al. (1990) and Hamilton (1994) for the discussion on parameter estimations and inferences in the VAR model with some unit roots.

[4]For empirical studies on the predictive content of asset prices for inflation and real output using data from advanced countries, see Sims (1992) for short-term interest rates, Estrella and Mishkin (1997) for term spreads, Campbell (1999) for dividend yields, and McCarthy (2007) for exchange rates.

[5]Andreasen et al. (2021) and Hiraki and Hirata (2020) further develop a model to extract market participants' long-term inflation expectations using break-even inflation as a proxy for the possible presence of various idiosyncratic factors in the inflation-linked bond market, such as liquidity premium and inflation risk premium.

an alternative empirical approach to quantitatively analyze the causal effects of future inflation on the macroeconomy. Specifically, we consider the identification of shocks to future inflation as a weighted average of real output and financial market innovations within the framework of a structural VAR model. We then empirically analyze the role of future inflation in the macroeconomy by estimating the dynamic causal effects of these shocks.

2.4 Identifying shocks to medium-term economic variation using the VAR model

In the VAR literature, several methodologies have been developed for extracting the sources of medium-term variation in macroeconomic time series.[6] Building on the work of Faust (1998) and Uhlig (2004), Francis et al. (2014) propose a method to identify productivity shocks using a maximum forecast error variance (MFEV) approach. The MFEV approach identifies a shock such that the contribution of the shock to the forecast error variance of a time-series process is maximized over all horizons up to a finite truncation horizon.[7] Barsky and Sims (2011) develop an MFEV approach to identify productivity *news* shocks as anticipated shocks in the productivity process. Specifically, they propose a *restricted* MFEV approach that imposes the restriction that the news shock does not affect productivity when it occurs. In this paper, the proposed identification of inflationary pressure shocks represents an application of the method of identifying anticipated shocks using the structural VAR model, introduced by Barsky and Sims (2011), to inflation.[8]

2.5 Monetary policy responses to inflation

Extensive literature has explored the role of a systematic behavior of monetary policy in the macroeconomy by estimating the monetary policy reaction function in the form proposed by Taylor (1993).[9] For example, Clarida et al. (2000) document a significant increase in the Federal

[6] See Ramey (2016) and Stock and Watson (2016) for a comprehensive literature survey and discussion of the identification of structural shocks in the VAR literature.

[7] Unlike the MFEV approach, Faust (1998) and Uhlig (2004) propose an approach that maximizes the shock's contribution at a predetermined finite horizon.

[8] In addition to analyzing the transmission mechanism of productivity shocks, some studies have employed the MFEV approach to identify structural shocks in the VAR model. For example, Angeletos et al. (2020) use the MFEV approach to identify single shocks that explain much of the business cycle variations in the macroeconomy. Ben Zeev et al. (2020) apply the restricted MFEV approach to identify anticipated monetary policy shocks that explain the future path of the federal funds rate. Kurmann and Otrok (2013) employ the MFEV approach to identify the shocks to the slope of the term structure of interest rate.

[9] In the original Taylor (1993) formulation, a short-term interest rate as a monetary policy instrument responds only to current inflation and output gaps. Further, Clarida et al. (1998, 1999, 2000) specify that the behavior of

Reserve's response to expected inflation after the 1980s in the U.S. Kuttner (2004) extend the methodology of Clarida et al. (2000) by using the central banks' own inflation and output forecasts to estimate the monetary policy reaction function and find that the policy function incorporating forecasts of inflation and output performs better than that based only on current output and inflation. Also, Ang et al. (2011) report a sharp but temporary decline in the Federal Reserve's response to current inflation in the early 1990s and the period (2001-2003). In Japan, Clarida et al. (1998), Jinushi et al. (2000), and Shibamoto (2008) argue that the BOJ has placed somewhat more emphasis on inflation than output stabilization, while Bernanke and Gertler (1999) argue that the Bank of Japan (BOJ) significantly weakened its commitment to inflation stabilization and attempted to stabilize the stock market. This study does not explicitly specify a policy reaction function but quantitatively estimates the systematic and dynamic responses of the policy stance to inflationary shocks. It then analyzes the differences in responses to different inflationary shocks: future inflationary pressures versus realized unexpected inflationary shocks.

3 Econometric methodology

3.1 Modeling unexpected inflation and inflationary pressure

First, we consider a model where inflation can be decomposed into expected and unexpected components. Suppose that the variable π_t represent inflation at period t. We consider the following model:

$$\pi_t = E_{t-1}(\pi_t) + \epsilon_t^c, \tag{1}$$

where $E_{t-1}(\pi_t)$ is the expected component of inflation at period t under the information set available at period $t-1$, and ϵ_t^c is the forecast error in inflation at period t that agents observe at the end of period t, namely an unexpected inflationary shock.

We assume that inflation at period t is well-characterized as a stochastic process driven by two inflationary shocks independent of each other. The first stochastic component is the unexpected inflationary shocks, $\epsilon_t^c, \epsilon_{t-1}^c, \cdots$. The second is the inflationary pressure shocks, $\epsilon_{t-1}^p, \epsilon_{t-2}^p, \cdots$, that agents had observed before period t. Then, we specify that inflation can be

policy instruments depends on the expected output gap and expected future inflation.

expressed in terms of the moving average (MA) representation as follows:

$$\pi_t = d^c(L)\epsilon_t^c + d^p(L)\epsilon_t^p, \tag{2}$$

where $d^c(L) = d_0^c + d_1^c L + \cdots$ and $d^p(L) = d_0^p + d_1^p L + \cdots$ are lag polynomials in the lag operator, L.[10] In equation (2), we impose restrictions, $d_0^c = 1$ and $d_0^p = 0$, on the MA representation so that the unexpected inflationary shock is equal to the forecast error in inflation at period t after conditioning on the information set available at period $t-1$ and that the inflationary pressure shock has no contemporaneous effect on current inflation.

Under inflation dynamics (2) with the restrictions $d_0^c = 1$ and $d_0^p = 0$, the inflationary pressure shock ϵ_t^p is measured as the shock that significantly explains *future* movements in inflation not accounted for by its own unexpected component. In a univariate context, it would be challenging to identify inflationary pressure shocks separately from unexpected inflation using only the observed inflation time series. Therefore, we assume that the real output and several forward-looking variables in the financial market at period t contain significant information for predicting future inflation. Then, we utilize the structural VAR model to identify the inflationary pressure shocks that come from surprise changes in those variables.

3.2 Identifying unexpected inflation and inflationary pressure shocks

We specify the VAR model in which the endogenous variables contain significant information on inflation dynamics. Let X_t denote a $K \times 1$ vector of time-varying observables in period t. The inflation is given by the first element of X_t, that is, $X_{1,t} = \pi_t$. We construct the following reduced-form VAR model:

$$A(L)X_t = e_t, \tag{3}$$

where $A(L) = I - A_1 L - \cdots - A_q L^q$ is a qth order matrix lag polynomial in the lag operator, L, of a coefficient matrix $A_j (j = 0, \cdots, q), A_0 = I$, and e_t denotes the $K \times 1$ vector of the reduced-form VAR innovations with a zero-mean of a covariance matrix of Σ_e.[11] We can express this

[10]To simplify the notation, no drift term in the inflation process has been included without loss of generality.

[11]In practice, since the VAR variables X_t generally have nonzero mean, the reduced-form VAR in (3) estimated in the empirical analysis contains a constant vector. In this subsection, to simply notation, no intercept in the VAR is made without loss of generality.

stochastic structure in terms of the following infinite vector MA (VMA) representation:

$$X_t = \Phi(L)e_t, \tag{4}$$

where $\Phi(L) = A(L)^{-1} = I + \Phi_1 L + \Phi_2 L^2 + \cdots$ is a matrix lag polynomial of a coefficient matrix $\Phi_\tau(\tau = 0, 1, \cdots), \Phi_0 = I$.

We derive the time-series variations of the VAR variables attributed to the structural shocks. Let the unexpected inflationary shock ϵ_t^c and inflationary pressure shocks ϵ_t^p be the first and second elements of the $K \times 1$ vector of the structural shocks $\epsilon_t = (\epsilon_t^c, \epsilon_t^p, \epsilon_t^{o'})'$. The space spanned by the unexpected inflation ϵ_t^c and inflationary pressure shocks ϵ_t^p is disentangled from the space spanned by other possible shocks ϵ_t^o in the following linear relation between the reduced-form VAR innovations e_t and structural shocks ϵ_t:

$$e_t = R^c \epsilon_t^c + R^p \epsilon_t^p + R^o \epsilon_t^o, \tag{5}$$

where R^c and R^p represent the impact vector for the responses of the VAR variables X_t to the unexpected inflation and inflationary pressure shocks, respectively, and R^o represents the impact matrix to other shocks. From (4) and (5), we can express the parts of the stochastic process of the VAR variables driven by the unexpected inflationary shocks and the inflationary pressure shocks as VMA of those past shocks, $\Phi(L)R^c\epsilon_t^c$ and $\Phi(L)R^p\epsilon_t^p$, respectively.

We consider the identification of structural shocks in the VAR model in a way that is consistent with the decomposition of stochastic sources of variation in inflation as discussed in Subsection 3.1. First, the unexpected inflationary shocks is identified as the reduced form innovation of inflation in a VAR system, $\epsilon_t^c = e_{1,t}$. This restriction reflects that the first element of the vector R^c is equal to one and that the first element of R^p and the first row of the matrix R^o are equal to zero. Second, the inflationary pressure shocks are identified as shocks that best explain the revisions of the agents' expectations about future inflation. To this end, we employ the restricted MFEV approach introduced by Barsky and Sims (2011).

To explain the restricted MFEV approach, we begin by relating the covariance matrix Σ_e of VAR innovations to the impact vector R^p of inflationary pressure shock. We first consider an arbitrary $K \times K$ orthogonalization matrix $\tilde{R}$ (e.g., Cholesky decomposition) such that it satisfies the condition, $\Sigma_e = \tilde{R}\tilde{R}'$. Suppose $\tilde{R}\gamma$ be a $K \times 1$ vector that is interpreted as an impact vector R^p, where a $K \times 1$ vector γ has unit length, $\gamma'\gamma = 1$. Suppose we have a vector γ and an orthogonalization matrix $\tilde{R}$. In this case, we can generate the impulse responses of the VAR variables to the inflationary pressure shock from the impact vector $R^p = \tilde{R}\gamma$.

Next, we consider the forecast error in inflation due to inflationary pressure shocks. We can express the h-period-ahead forecast error in the VAR variables as follows:

$$X_{t+h} - E_{t-1}X_{t+h} = \sum_{\tau=0}^{h} \Phi_\tau e_{t+h-\tau}, \tag{6}$$

where the equality use equation (4). Thus, the h-period-ahead forecast error in inflation can be expressed as follows:

$$X_{1,t+h} - E_{t-1}X_{1,t+h} = \sum_{\tau=0}^{h} \Phi_{1,\tau} e_{t+h-\tau}, \tag{7}$$

where $\Phi_{1,\tau}$ is the first row of the matrix of the MA coefficients Φ_τ. From equation (5), the h-period-ahead forecast error in inflation due to inflationary pressure shocks can be expressed as follows:

$$\sum_{\tau=0}^{h} \Phi_{1,\tau} R^p \epsilon^p_{t+h-\tau} = \sum_{\tau=0}^{h} \Phi_{1,\tau} \tilde{R}\gamma \epsilon^p_{t+h-\tau}. \tag{8}$$

We identify inflationary pressure shocks by choosing a vector γ to maximize the forecast error variance of inflation for h periods ahead, but with the restriction that they do not affect inflation when the shock occurs. The share of the forecast error variance of inflation attributable to inflationary pressure shocks at horizon h is

$$\Omega_{1,p}(h) = \frac{\sum_{\tau=0}^{h} \Phi_{1,\tau} \tilde{R}\gamma E(\epsilon^p_{t+h-\tau}\epsilon^p_{t+h-\tau})\gamma' \tilde{R}' \Phi'_{1,\tau}}{\sum_{\tau=0}^{h} \Phi_{1,\tau} \Sigma_e \Phi'_{1,\tau}} = \frac{\sum_{\tau=0}^{h} \Phi_{1,\tau} \tilde{R}\gamma\gamma' \tilde{R}' \Phi'_{1,\tau}}{\sum_{\tau=0}^{h} \Phi_{1,\tau} \Sigma_e \Phi'_{1,\tau}}, \tag{9}$$

where the variance of inflationary pressure shocks is normalized to one. We choose the vector γ by solving the following restricted optimization problem:

$$\hat{\gamma} = \arg\max_{\gamma} \Omega_{1,p}(h), \tag{10}$$

s.t.

$$\iota' \tilde{R}\gamma = 0, \tag{11}$$

$$\gamma'\gamma = 1, \tag{12}$$

where ι denotes the $K \times 1$ selection vector with one in the first place and zeros elsewhere. The restriction (11) imposes that the inflationary pressure shock has no contemporaneous effect on inflation. Our framework measures the inflationary pressure shocks as anticipated shocks to future inflation caused by sudden changes in VAR variables other than the inflation itself.

3.3 Reduced-form VAR model specification

We consider the following variables in constructing the VAR model. As the measure of inflation, we include $\pi_t = 400 \log(P_t/P_{t-1})$, where P_t is the quarterly consumer price index (CPI) for all items less fresh food (CPI).[12] In addition to the measure of inflation, we include five macroeconomic variables: real output and four financial variables. The real output is measured by the real gross domestic product (GDP) (Real GDP). The four financial variables are the shadow policy rate as a proxy for monetary policy stance in Japan (shadow policy rate), 10-year Japanese government bond yield as the measure of long-term interest rate (10-year treasury yield), the dividend yield as the measure of equity risk premium (dividend/stock price), and the nominal effective exchange rate (effective exchange rate). See the Appendix for more detailed information on those variables in the VAR model. Real GDP and effective exchange rate are expressed in logarithm and multiplied by 100. The dividend yield is expressed in logarithm. We conduct a preliminary analysis in the Online Appendix to confirm the significant information content of the endogenous variables in the VAR model for inflation dynamics.

The reduced-form quarterly VAR model is estimated over the period from the first quarter of 1983 to the fourth quarter of 2018. Our dataset for the VAR estimation covers the period from the trough of the ninth business cycle to the peak of the sixteenth cycle as defined by Japan's Cabinet Office. The lag length q in the reduced-form VAR estimation is set to five quarters. We confirm that taking five-quarter lags is sufficient to capture the system dynamics.[13]

[12] We confirm that alternative price indexes, CPI for all items and CPI for all items excluding fresh food and energy, produce similar results.

[13] The Bayesian information criterion (BIC) selects one lag, and the Akaike information criterion (AIC) selects two lags. We perform a modified likelihood ratio test, proposed by Sims (1980), to check whether taking one or two lags is sufficient. The chi-squared statistics indicate that the null hypothesis of one or two lags is rejected at the 5% significance level against the alternative of five lags. They also indicate that conventional significance levels do not reject the null hypothesis of five lags, as against the alternative of six lags. Moreover, the estimated results are insensitive when six lags are employed.

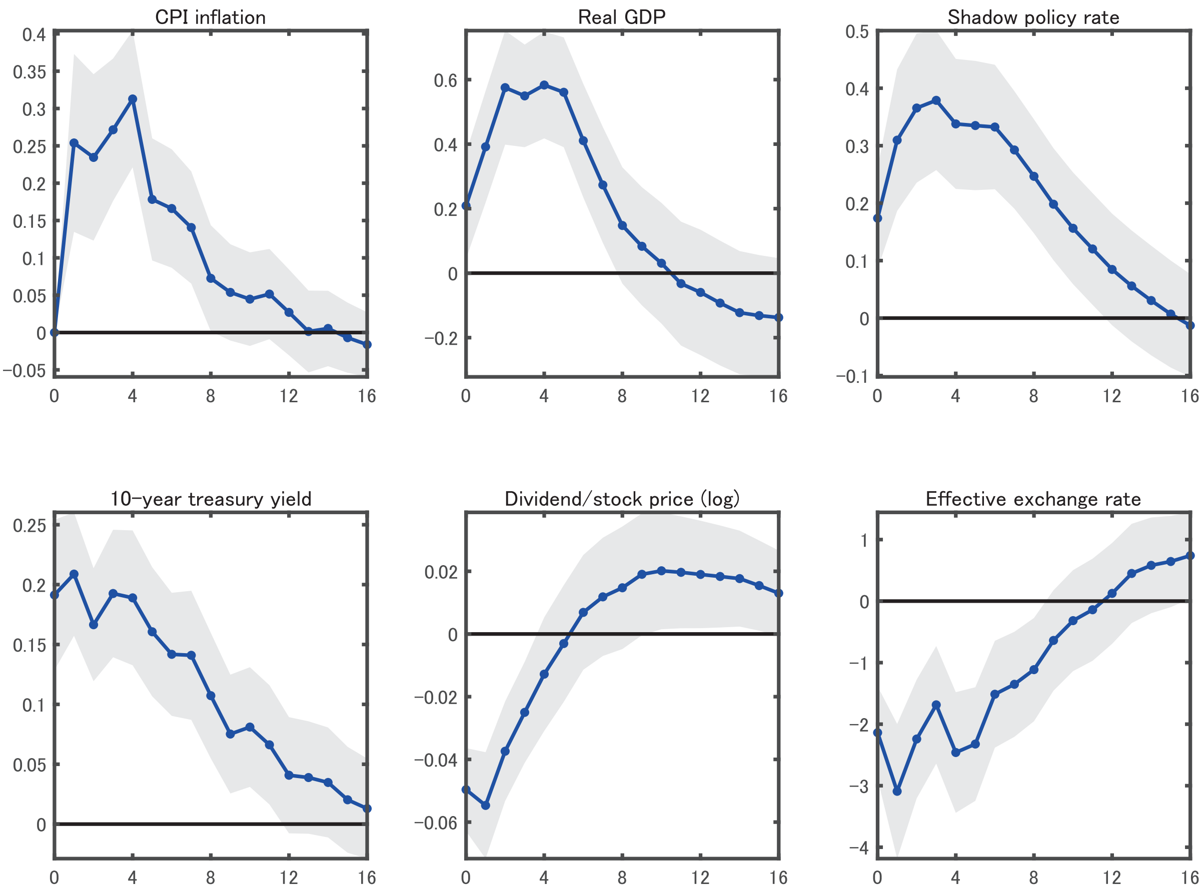

Figure 1: Estimated responses to an inflationary pressure shock

Notes: The solid line with circles represents the point estimates of the impulse responses to one standard deviation inflationary pressure shock. The shaded areas denote one-standard-error bands, calculated using 1000 bootstrap samples. We set the lag length to five quarters in the reduced-form vector autoregressive (VAR) estimation. Estimation samples span from the first quarter of 1983 to the fourth quarter of 2018.

4 Empirical results and discussion

4.1 Dynamic causal effect of an inflationary pressure shock

Figure 1 summarizes the estimated impulse response functions to an inflationary pressure shock. We set the horizon in the identification problem at $h = 16$, that is, we identify the inflationary pressure shock as the shock orthogonal to inflation innovations that best account for future inflation movements over a four-year horizon. Inflationary pressure shocks are normalized to have unit variance and signed to positively affect the inflation four-quarter ahead. The solid line with the circles indicates the estimated response for the VAR variables for up to 16 quarters. The shaded areas denote one-standard-error bands, calculated using 1000 bootstrap samples.

Our identified inflationary pressure shocks are likely to be characterized as shocks to the demand side. As shown in the upper-left panel of Figure 1, although it explains by construction none of the movements in inflation at the time of impact, an inflationary pressure shock causes inflation to rise persistently for about two years, peaking at about 0.2 to 0.3 percentage points. Furthermore, as shown in the upper-middle panel of the figure, the real GDP rises by about 0.2 percentage point at the time of the shock, reaches a peak response of about 0.6 percentage points about one and half years after the shock, and then gradually returns to zero. This pattern implies that inflationary pressure shocks are attributable to shifts in aggregate demand.

Moreover, forward-looking variables in financial markets are immediately affected in response to an inflationary pressure shock. As shown in the upper-right panel of Figure 1, the shadow policy rate increases by about 0.2 percentage points on impact and then remains about 0.3 percentage points higher than the pre-shock value for about two years. This result indicates that the BOJ has a preference for systematic policy responses, changing its policy rate roughly in line with future increases in inflation. As shown in the bottom-left panel of the figure, the long-term interest rate also rises by about 0.2 percentage points. This result suggests that while the nominal safe interest rate increases against inflationary pressures, the change in the real interest rate is minimal. As shown in the bottom-middle and bottom-right panels of the figure, the log of dividend yield and the effective exchange change rate decrease immediately. This result suggests that our inflationary pressure shock is associated with a lower equity risk premium and a weaker yen.

The dynamic causality of an unexpected inflationary shock to the macroeconomy is quite different from that of an inflationary pressure shock. Figure 2 summarizes the estimated impulse response functions to an unexpected inflationary shock. We find that an unexpected inflationary shock associated with an immediate spike in inflation causes the real GDP to decline persistently, indicating a supply or cost-push factor. In response to the unexpected inflationary shock, both shadow short and long rates persistently rise. While an unexpected inflationary shock is associated with yen depreciation, its impact on dividend yields is limited.

4.2 Identified inflationary pressure shocks

In this subsection, we examine the time series of structural shocks identified using the VAR model. For this purpose, it is helpful to decompose inflation fluctuations into inflationary pressure shocks and unexpected inflationary shocks. Based on our empirical results in subsection

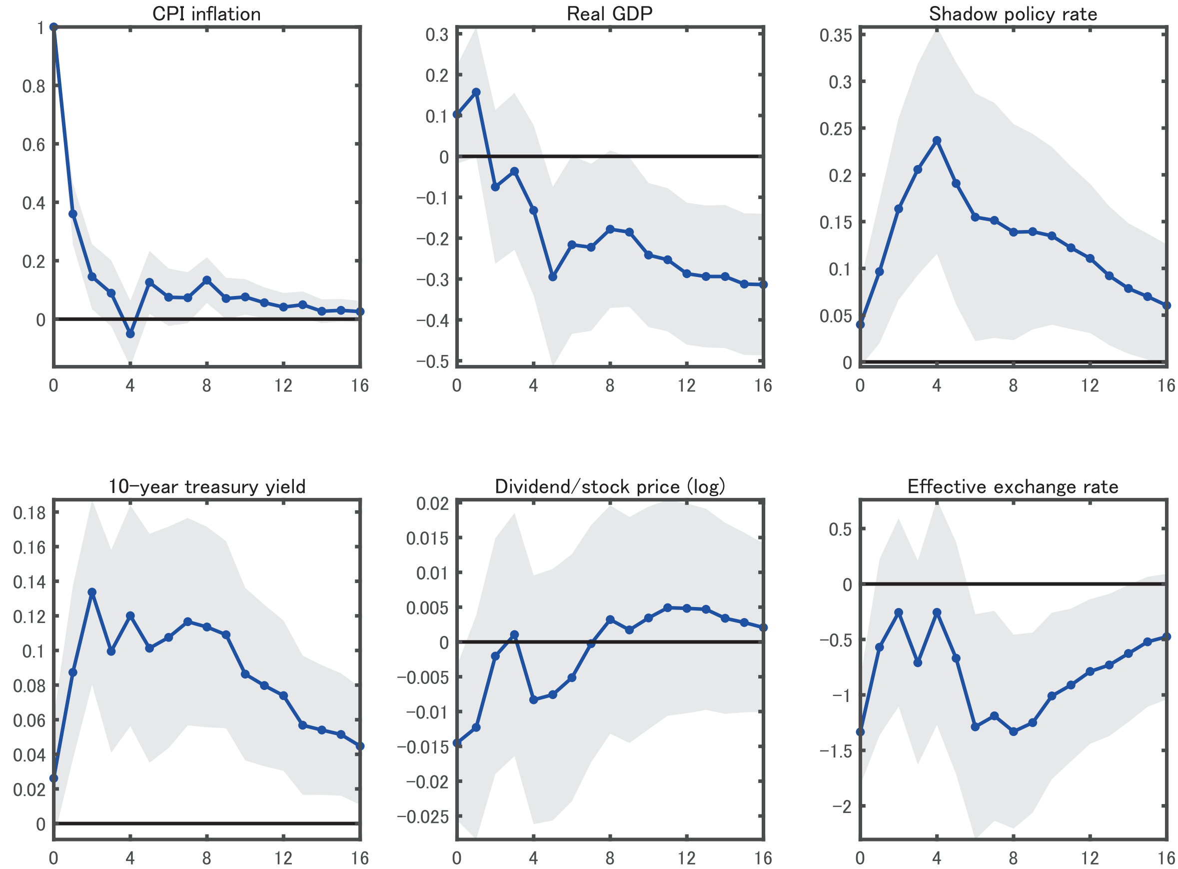

Figure 2: Estimated responses to an unexpected inflationary shock

Notes: The solid line with circles represents the point estimates of the impulse responses to an unexpected inflationary shock. The shaded areas denote one-standard-error bands, calculated using 1000 bootstrap samples. We set the lag length to five quarters in the reduced-form vector autoregressive (VAR) estimation. Estimation samples span from the first quarter of 1983 to the fourth quarter of 2018.

4.1, we conjecture that, on the one hand, inflationary pressure shocks would capture exogenous changes in demand-pull pressures. On the other hand, we conjecture that unexpected inflationary shocks would capture cost-push factors. Consequently, we investigate what qualitatively and specifically explains the differences between the two inflationary shock types. We then use the identified structural shocks to capture the historical sources of inflation dynamics over the sample period.

First, to explore the qualitative differences between inflationary pressure shocks and unexpected inflationary shocks, we examine the associations between the identified inflationary shocks and the candidate drivers behind the global business cycles. Given the integration of the Japanese economy into the global economy, changes in the global economic environment that are exogenous to the Japanese economy can partly explain the fluctuations in Japan's inflation.

Referring to the estimated dynamic causal effects of inflationary pressure shocks and unexpected inflationary shocks on the macroeconomy in the previous subsection, they are expected to be associated differently with signs of demand-pull inflation due to changes in external demand and with signs of cost-push inflation due to changes in raw material and resource prices. From this analytical viewpoint, we conduct the following linear regression of each of the identified inflationary shocks on global economic factors:

$$\hat{\epsilon}_t^j = \delta_1^j + \delta_g^{j\prime} g_t + \xi_t^j \text{ for } j = p, c, \tag{13}$$

where g_t denotes the vector of the regressors consisting of global economic variables expected to have substantive effects on the Japanese economy.

We consider the following regressors in equation (13): change in U.S. shadow policy rate (USSPR), change in U.S. 10-year treasury bond and 3-month treasury bill spread (USTERM), change in U.S. 3-month London Interbank Offered Rate (LIBOR) and treasury bill spread (USTED), the innovation in U.S. stock market option-based implied volatility or VIX data computed as the residual from an AR(4) model (VIX), the log changes in oil prices (POIL), and the log changes in commodity prices (PCOM).[14] We use USSPR as the short-term measure of U.S. monetary policy (Sims, 1980, 1992; Bernanke and Blinder, 1992). While USSPR could be negatively associated with inflationary shocks under the premise that U.S. monetary policy has a causal effect on the global economy if exogenous changes in the policy stance dominate USSPR, we expect that USSPR is positively associated with inflationary shocks if the policy rate cuts by the Federal Reserve work as a signal presaging future increases in U.S. output and inflation.(Romer and Romer, 2000; Ellingsen and Söderstrom, 2001; Claus and Dungey, 2012; Campbell et al., 2012; Nakamura and Steinsson, 2018). We also use USTERM as the leading indicator for U.S. economic activity and expect that USTERM is positively associated with inflationary shocks.[15] We use USTED as a measure of the credit risk and liquidity risk in the global market.[16] Motivated by Bloom (2009), we use USVIX to measure the shocks to global uncertainty. We expect that USTED and USVIX are negatively associated with inflationary shocks. Finally, we employ POIL and PCOM as measures of exogenous cost-push factors. We

[14]See the Appendix for more detailed information for the global economic variables.

[15]For example, Kurmann and Otrok (2013) argue that the main driver of fluctuations in the slope of the term structure of interest rate is news about future total factor productivity.

[16]For an early discussion of commercial paper and treasury bill spread as measures of market liquidity, see, for example, Friedman and Kuttner (1993).

expect that these two variables are positively associated with inflationary shocks. Since these two variables are highly correlated, we add them separately as regressors in the regression model.[17]

Table 1 reports the estimation results for the regression (13). As shown in columns [1] and [2] of Table 1, the inflationary pressure shock ($\hat{\epsilon}_t^p$) is positively associated with USSSR and USTERM, which are statistically significant at the 1% level. Also, the inflationary pressure shock is negatively associated with USTED and VIX, suggesting that the surge in global credit risk and uncertainty are the main driving forces of deflationary pressure in Japan. Meanwhile, the inflationary pressure shock is not associated with global cost-push factors, such as POIL and PCOM. In contrast, as shown in columns [3] and [4] of Table 1, the unexpected inflationary shock ($\hat{\epsilon}_t^c$) is positively associated with POIL and PCOM, which is statistically significant at the 1% level. These results support our conjecture that inflationary pressure shocks are inherently demand-pull factors, not cost-push factors.

Next, we report the time series of structural shocks identified in the VAR model. Figure 3 displays the time series of inflationary pressures and unexpected inflationary shocks. The bars in the upper and lower panels indicate inflationary pressures and unexpected inflationary shocks, respectively, as identified using the estimated VAR model. The estimated time series of the shocks identified from the VAR model tend to be noisy, since both of them are serially uncorrelated by construction. We report the MA of the shock from the previous four quarters, that is, $\sum_{\tau=0}^{3} \hat{\epsilon}_{t-\tau}^p/4, \sum_{\tau=0}^{3} \hat{\epsilon}_{t-\tau}^c/4$, in Figure 3 for ease of visual interpretation. The shaded areas show periods of recession in Japan, as defined by the Cabinet Office.

Our empirical results suggest that the Japanese economy faced large fluctuations in inflationary pressure shocks during Japan's bubble economy and the subsequent prolonged economic slump. In the upper panel of Figure 3, we can see the large upward swings representing inflationary pressure shocks during Japan's bubble economy around 1990. We then see a sustained trough in the decade from the mid-1990s to the mid-2000s. Since the mid-2000s, the inflationary pressure shocks have been swinging in line with the timing of the business cycle. The historical evolution of inflationary pressure shocks has a completely disparate feature from that captured by the time series of unexpected inflationary shocks shown in the lower panel of the figure.

[17] The Pearson's correlation coefficient between POIL and PCOM is 0.71.

Table 1: Identified inflationary shocks and global economic factors

Dependent variable	$\hat{\epsilon}_t^p$		$\hat{\epsilon}_t^c$	
	[1]	[2]	[3]	[4]
Regressor				
USSPR	0.50**	0.50**	-0.18	-0.13
	(0.18)	(0.17)	(0.13)	(0.13)
USTERM	0.77**	0.77**	0.24	0.28*
	(0.21)	(0.21)	(0.14)	(0.14)
USTED	-1.00**	-0.99**	0.39	0.40
	(0.28)	(0.28)	(0.22)	(0.22)
USVIX	-0.037*	-0.039**	-0.051**	-0.050**
	(0.016)	(0.016)	(0.016)	(0.016)
POIL	-0.02		1.35**	
	(0.51)		(0.41)	
PCOM		-0.34		2.44**
		(0.98)		(0.96)
Adjusted R-squared	0.22	0.22	0.18	0.16

Notes: This table shows the estimated coefficients in equation (13). The dependent variable is the identified inflationary pressure shocks $\hat{\epsilon}_t^p$ for regressions [1] and [2] or unexpected inflationary shocks $\hat{\epsilon}_t^c$ for regressions [3] and [4], respectively. The constant is included as a control variable in the regressions. The numbers in parentheses are White (1980) heteroskedasticity-robust standard errors for ordinary least squares. **and *indicate statistical significance at the 1 and 5% levels, respectively. The sample spans from the first quarter of 1983 to the fourth quarter of 2018. USSSR: change in U.S. shadow policy rate, USTERM: change in U.S. 10-year treasury bond and 3-month treasury bill spread, USTED: change in U.S. 3-month London Interbank Offered Rate (LIBOR) and treasury bill spread, USVIX: innovation in U.S. VIX data computed as the residual from an AR(4) model, POIL: log changes in oil prices, PCOM: log changes in commodity prices.

4.3 Historical evolution of inflation due to inflationary pressures

In this subsection, we report the historical evolution of inflation due to identified inflationary pressure shocks using our structural VAR model. In particular, we examine whether inflationary pressure shocks capture stochastic changes in trend inflation in inflation dynamics. We do not explicitly formulate trend inflation in our structural VAR model. Nonetheless, we conjecture that inflationary pressure shocks identified as shocks that capture medium-term inflation variations can encapsulate stochastic changes in low-frequency movements of trend inflation. Therefore, to verify the plausibility of our conjecture, we decompose the actual inflation into a series due to inflationary pressures or unexpected inflationary shocks.

Figure 4 plots the fitted values of CPI inflation from the VAR model due to identified inflationary pressure shocks and unexpected inflationary shocks from the first quarter of 1983

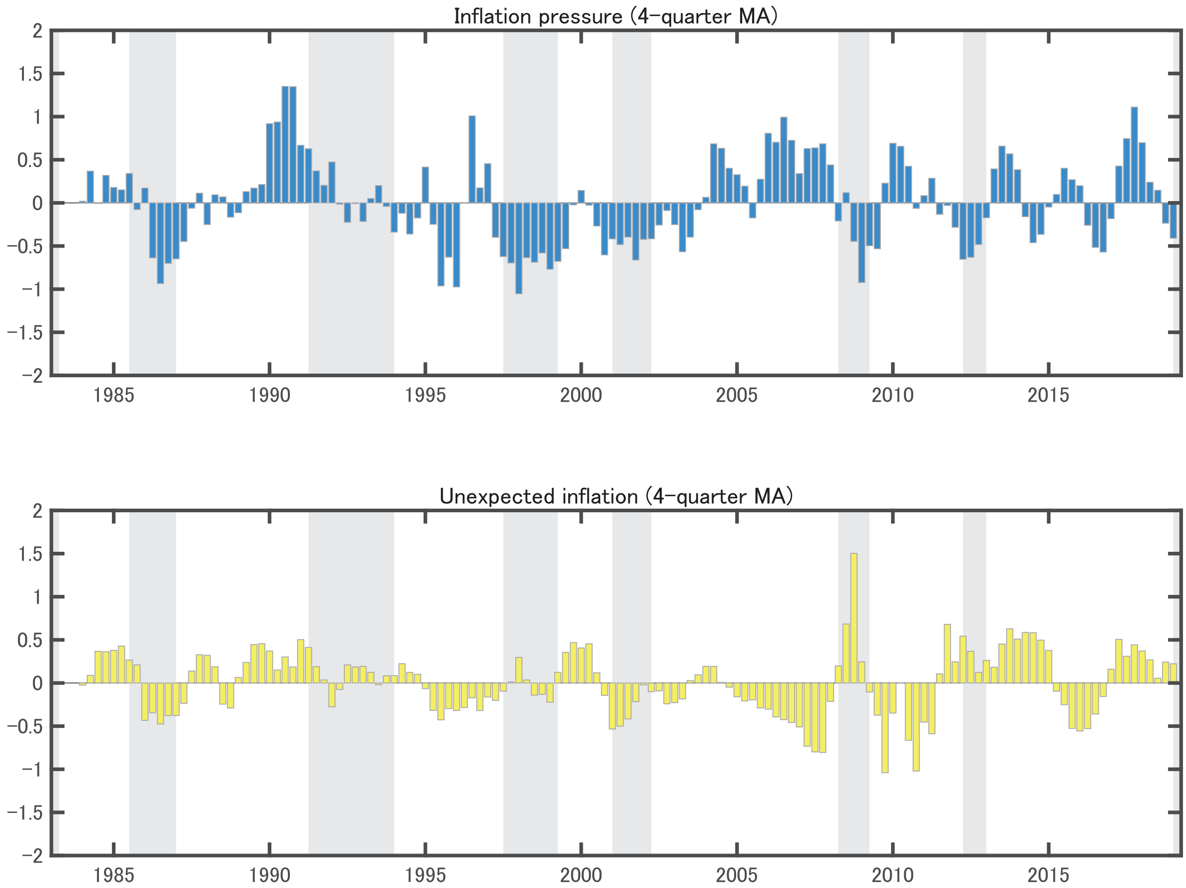

Figure 3: Identified inflationary pressure and unexpected inflationary shocks

Notes: The bars in the upper and lower panels indicate the 4-quarter MA of the inflationary pressure and unexpected inflationary shocks, respectively, identified using the estimated vector autoregressive (VAR) model (3) with the restricted optimization problems (10), (11), and (12). The shaded areas show periods of recession in Japan, as defined by the Cabinet Office. We set the lag length to five quarters in the reduced-form VAR estimation. Estimation samples span from the first quarter of 1983 to the fourth quarter of 2018.

to the fourth quarter of 2018. The blue and yellow bars show the series explained by the inflationary pressure and unexpected inflation shocks, respectively, using the VAR model. The solid line indicates the estimated stochastic component before the decomposition.

We can visually identify two distinctive properties of the inflationary pressure shocks in inflation dynamics. First, inflation dynamics due to the identified inflationary pressure shocks are eliminated from variations due to the transitory component. This result reflects that unexpected inflationary shocks consequently capture a large part of the innovations of the transitory component of inflation, while inflationary pressure shocks can explain the variation in inflation independent of unexpected inflationary shocks.

Second, inflation dynamics due to identified inflationary pressure shocks are broadly in line

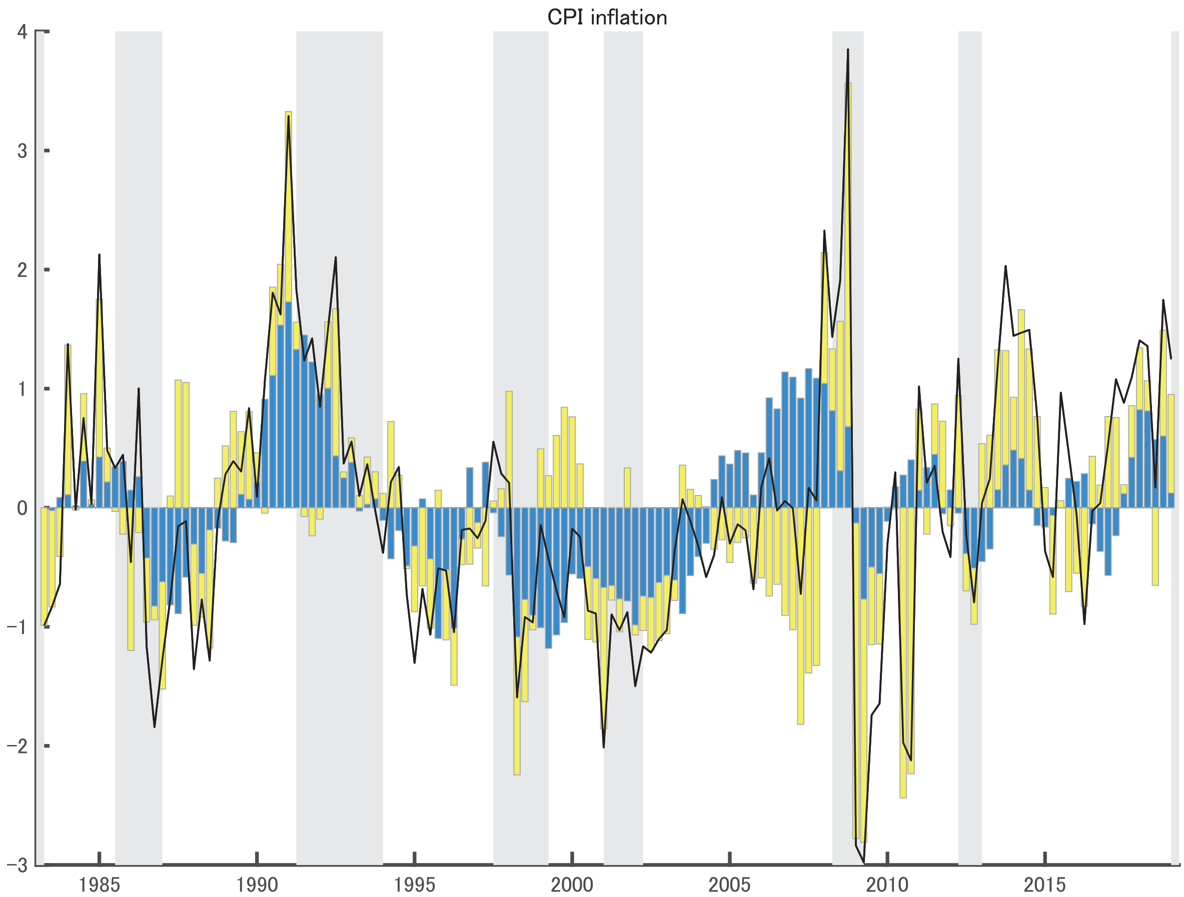

Figure 4: Inflation dynamics due to inflationary pressures and unexpected inflationary shocks

Notes: The series are displayed as deviations from the deterministic component. The blue and yellow bars show the series explained by the inflationary pressure and unexpected inflationary shocks shocks, respectively, using the VAR model. The solid line indicate the estimated stochastic component before the decomposition. The gray-shaded areas show periods of recession in Japan, as defined by the Cabinet Office. The sample period spans from the first quarter of 1983 to the fourth quarter of 2018. We set the lag length to five quarters in the reduced form VAR estimation.

with the stochastic changes in the inflation trend.[18] In particular, we can see that during Japan's asset price bubble around 1990, the Japanese inflation rose along with a shift in the stochastic trend. Since the bubble burst, inflation has declined with a stochastic trend over more than ten years. During this period, inflation decreased during the recessionary phase, while the decline was temporarily limited during the recovery phase. Since the mid-2000s, the trend has changed along the business cycle, albeit modestly. These timings of stochastic changes in the trend are broadly consistent with those of inflation dynamics that can be explained by the inflationary pressure shocks identified through the VAR model. This result suggests

[18]We confirm that the UCSV model using Japanese data support the following discussion of stochastic changes in trend inflation in Japan. See the Online Appendix for details of the UCSV model and its estimation results.

Table 2: Share of the forecast error variance explained by unexpected inflationary shocks or inflationary pressure shocks for inflation, real output, and financial variables.

Variable X_k ($k = 1, \cdots, 6$)	[1]		[2]		[3]		[4]		[5]		[6]	
Shock ϵ^j ($j = c, p$)	ϵ^c	ϵ^p	ϵ^c	ϵ^p	ϵ^c	ϵ^p	ϵ^c	ϵ^p	ϵ^c	ϵ^p	ϵ^c	ϵ^p
Horizon (h)												
0	100	0	1.1	8.3	0.8	22.2	0.4	34.6	2.7	49.6	9.4	44.3
1	86.8	8.7	1.8	19.1	1.9	32.5	2.9	47.7	2.0	44.4	4.7	48.6
4	62.3	29.1	1.2	43.9	7.8	44.5	9.2	55.7	1.2	30.3	4.6	41.0
8	58.0	33.0	3.2	41.0	9.3	48.7	12.1	52.8	1.0	20.9	10.0	39.8
16	56.1	32.2	7.5	25.3	11.0	45.3	14.1	47.0	1.1	19.2	12.6	34.6

[1] CPI inflation
[2] Real GDP (log)
[3] Shadow policy rate
[4] 10-year treasury yield
[5] Dividend/stock price (log)
[6] Effective exchange rate (log)

Notes: The entries are $\Omega_{k,c}(h)$ and $\Omega_{k,p}(h)$ for $k = 1, \cdots, 6$, which show the percentage share of the variance of the forecast error by the variable described in the upper header at a given horizon h as explained by the unexpected inflationary shocks ϵ^c and inflationary pressure shocks ϵ^p, respectively. The results are computed based on the vector autoregressive (VAR) model (3) with the restricted optimization problems (10), (11), and (12) over the sample period from the first quarter of 1983 to the fourth quarter of 2018. We set the lag length to five quarters in the reduced-form VAR estimation.

that inflationary pressure shocks capture the driving forces of stochastic changes in the trend underlying inflation dynamics.

4.4 Variance decompositions

We assess the contributions of the inflationary pressure and unexpected inflationary shocks to macroeconomic dynamics. Specifically, given the inflationary pressure shocks ϵ^p and unexpected inflationary shocks ϵ^c identified by the structural VAR model, we calculate the respective contributions by ϵ^p and ϵ^c to the forecast error variance of macroeconomic variables.

Table 2 presents the forecast error variance decomposition results. The entries are $\Omega_{k,c}$ and $\Omega_{k,p}$ for $k = 1, \cdots, 6$, which show the percentage share of the variance of the forecast error by the VAR variable described in the upper header at a given horizon h as explained by the unexpected inflationary shocks ϵ^c and inflationary pressure shocks ϵ^p, respectively.

The inflationary pressures explain a large proportion of the current and future fluctuations in Japan's inflation, real output, and financial markets since the 1980s. As shown in Table 2, the identified inflationary pressure shocks ϵ^p explain more than 30% of the variation in CPI inflation in the medium- to long-term. It also greatly contributes to the current and future fluctuations in the real output and financial markets; quantitatively, it contributes approximately more than 20–50% to the real output, shadow policy rate, long-term rate, dividend yield, and exchange rate. This result suggests that inflationary pressures were one of the primary sources behind the dynamics of inflation, business cycles, and financial markets during Japan's asset price bubble and the subsequent prolonged economic slump.

4.5 Empirical results from U.S. data

In this subsection, we conduct an international comparison to deepen our understanding of the role that inflationary pressures play in the business cycle and financial markets. We conjecture that the economic significance of inflationary shocks depends on a country's macroeconomic environment and the preference of its monetary policy authority. Therefore, if we use our empirical framework in a country different from Japan, we expect to find similarities and differences in the causal relationships between inflation, business cycles, and financial markets. Additionally, quantitative cross-country comparisons of these relationships would help clarify the significance of the stability of inflation forecasts.

On the one hand, we identify a similarity between the inflation dynamics in Japan and the U.S. In particular, as described in the Online Appendix, the volatility of trend inflation innovations in Japan has declined substantially since the 1980s. This pattern is comparable to that of the U.S., as reported in Stock and Watson (2007). This time-series feature suggests that trend inflation in both countries tends to develop stably, despite differences in levels.

On the other hand, we can recognize significant differences in inflation and business cycles between Japan and the U.S. In particular, Japan faced a prolonged economic slump with low inflation, growth, and interest rates for decades after the burst of its bubble economy in the early 1990s. In contrast, the U.S. and other advanced countries experienced a period of macroeconomic stability known as the Great Moderation from the 1980s until before the 2007-2008 Global Financial Crisis.[19] As pointed out by Stock and Watson (2005), the business cycles in

[19] Blanchard and Simon (2001) report decline in the volatility of economic activity and inflation in the U.S. Using a structural time-varying coefficient VAR model, Canova et al. (2007) examine the nature and sources of structural changes in the dynamics of output growth and inflation in the U.S., Euro area, and the U.K. and report on their similarities and differences across countries.

Japan are likely to be different from those in advanced countries, including the U.S.

Furthermore, previous studies have highlighted the differences between the monetary policy preferences of central banks in the U.S. and Japan. In particular, the Federal Reserve has adopted an aggressive policy to stabilize the macroeconomy since the 1980s. In contrast, Bernanke (2000) and Kuttner (2014) point out that Japan's policy response has been conservative and lacked decisiveness.[20]

We demonstrate how our empirical framework can facilitate a quantitative assessment of the aforementioned discussions. Specifically, we present the empirical results of applying our empirical framework to the U.S. time-series data. In particular, we investigate differences in the dynamic causality of inflationary pressure and unexpected inflationary shocks between Japan and the U.S.

We report the results for estimating the VAR model (3) with the restrictions (10), (11), and (12), using the time-series data of the U.S. macroeconomy from the first quarter of 1983 to the fourth quarter of 2018.[21] We include the four-quarter lags of the endogenous variables in the VAR model for the U.S. Figure 5 plots the estimates of inflation dynamics due to inflationary pressure shocks using the VAR model with the Federal Reserve Bank of Cleaveland's 10-year expected inflation and realized CPIxFE inflation. Figures 6 and 7 show the estimated impulse response functions to an inflationary pressure shock and an unexpected inflationary shock, respectively. Table 3 presents the results of the forecast error variance decomposition.

From the above tables and figures, we can see that inflationary pressures account for a slowly-varying trend of inflation in the U.S., as in the case of Japan. As shown in Figure 5, inflation dynamics in the U.S. due to inflationary pressure shocks have shifted moderately throughout the investigated period, even though there was a transitory rise in inflation in the early 1990s and a transitory decline in inflation in the late 1990s, early 2000s, and during the 2007-2008 Global Financial Crisis. This pattern is roughly coincident with the evolution of expected inflation over the 10-year horizon estimated by the Federal Reserve. This result suggests that the inflationary pressure shocks identified from our structural VAR model parsimoniously capture the driving forces of stochastic changes in expected inflation in the long term.

In contrast to the case of Japan, U.S. monetary policy has changed its stance quite ag-

[20] Jinushi et al. (2000) also make a similar argument as Bernanke (2000) and Kuttner (2014), but point out that the BOJ's policy stance has changed to respond more strongly to inflation than to economic activity, compared to the mid-1980s and earlier.

[21] See the Appendix for the time-series data on the U.S. macroeconomy that we use in the analysis.

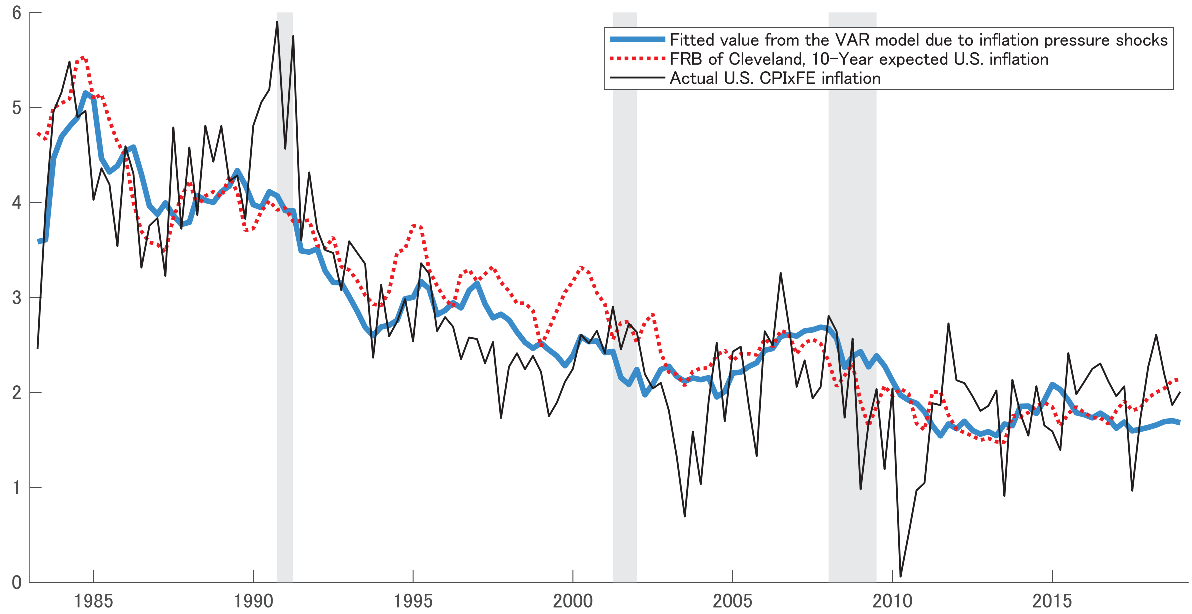

Figure 5: Estimates of inflation dynamics due to the inflationary pressure shocks using the VAR model: The case of the U.S.

Notes: The sample period spans from the first quarter of 1983 to the fourth quarter of 2018. The blue bold line indicates the series explained by the inflationary pressure shocks using the vector autoregressive (VAR) model. We set the lag length to four quarters in the reduced-form VAR estimation.

gressively in response to inflationary pressures. As shown in the upper-right panel of Figure 6, an inflationary pressure shock that causes inflation to rise by about 0.1 percentage point causes the U.S. shadow policy rate to increase by about 0.3 percentage points on impact and continue to rise persistently for about three years, peaking at about 0.6 percentage points. As shown in the bottom-left panel of the figure, the long-term interest rate also rises by about 0.4 percentage points. This result suggests that real interest rates have risen sharply against inflationary pressures, in contrast to the case of Japan. Also, as shown in the bottom-middle panel of the figure, the log of dividend yield increases vey steeply immediately. Consequently, while real GDP rises temporarily in the immediate aftermath of the shock, its medium-term impact is relatively limited. These findings imply that the Federal Reserve prefers to preemptively and proactively change financial conditions to achieve its goal of macroeconomic stability in response to inflationary pressures, which are potentially demand-pull factors.

Conversely, the Federal Reserve makes slight changes in its policy stance in response to unexpected inflation. As shown in the upper-middle panel of Figure 7, an unexpected inflationary shock has a persistent and statistically significant impact on real GDP. Nevertheless, as shown

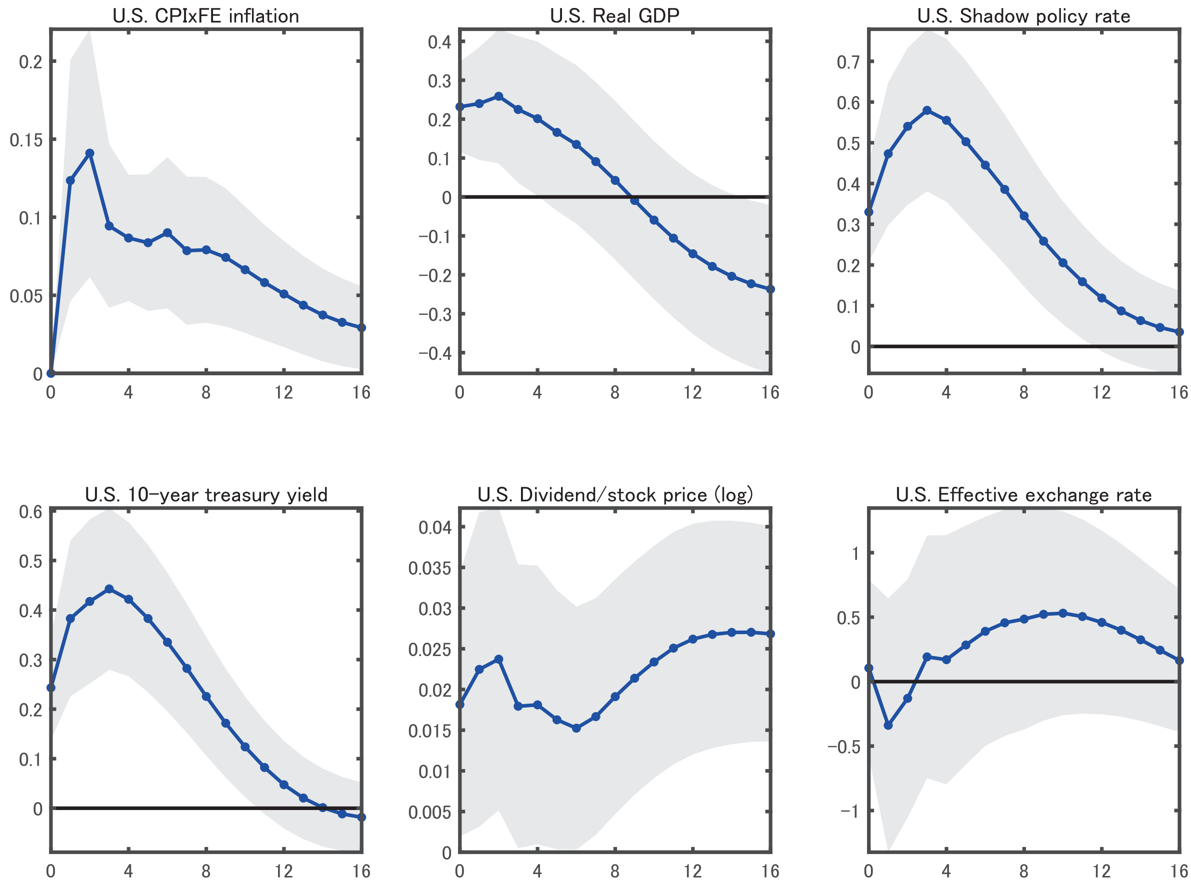

Figure 6: Estimated responses to an inflationary pressure shock: The case of the U.S.

Notes: The solid line with circles represents the point estimates of the impulse responses to one standard deviation inflationary pressure shock. The shaded areas denote one-standard-error bands, calculated using 1000 bootstrap samples. We set the lag length to four quarters in the reduced-form vector autoregressive (VAR) estimation. Estimation samples span from the first quarter of 1983 to the fourth quarter of 2018.

in the upper-right and bottom-left panels of the figure, in contrast to the case of Japan, the short- and long-term interest rates have a limited reaction to unexpected inflation. Also, as shown in the bottom-middle panel of the figure, the log of dividend yield rises persistently. These findings imply that the Federal Reserve has a preference to be less involved in realized inflation despite being proactive when dealing with future inflationary pressures.

The contributions of inflationary pressures to macroeconomic dynamics differ considerably between Japan and the U.S. As shown in Table 3, inflationary pressure shocks explain more than 60% of the forecast error variance of U.S. short- and long-term interest rates, suggesting that they are the primary sources of fluctuations in short- and long-term interest rates. This result is comparable to the Japanese case and implies that both the BOJ and the Federal Reserve tend to pursue a policy to stabilize future inflation. However, inflationary pressure shocks explain

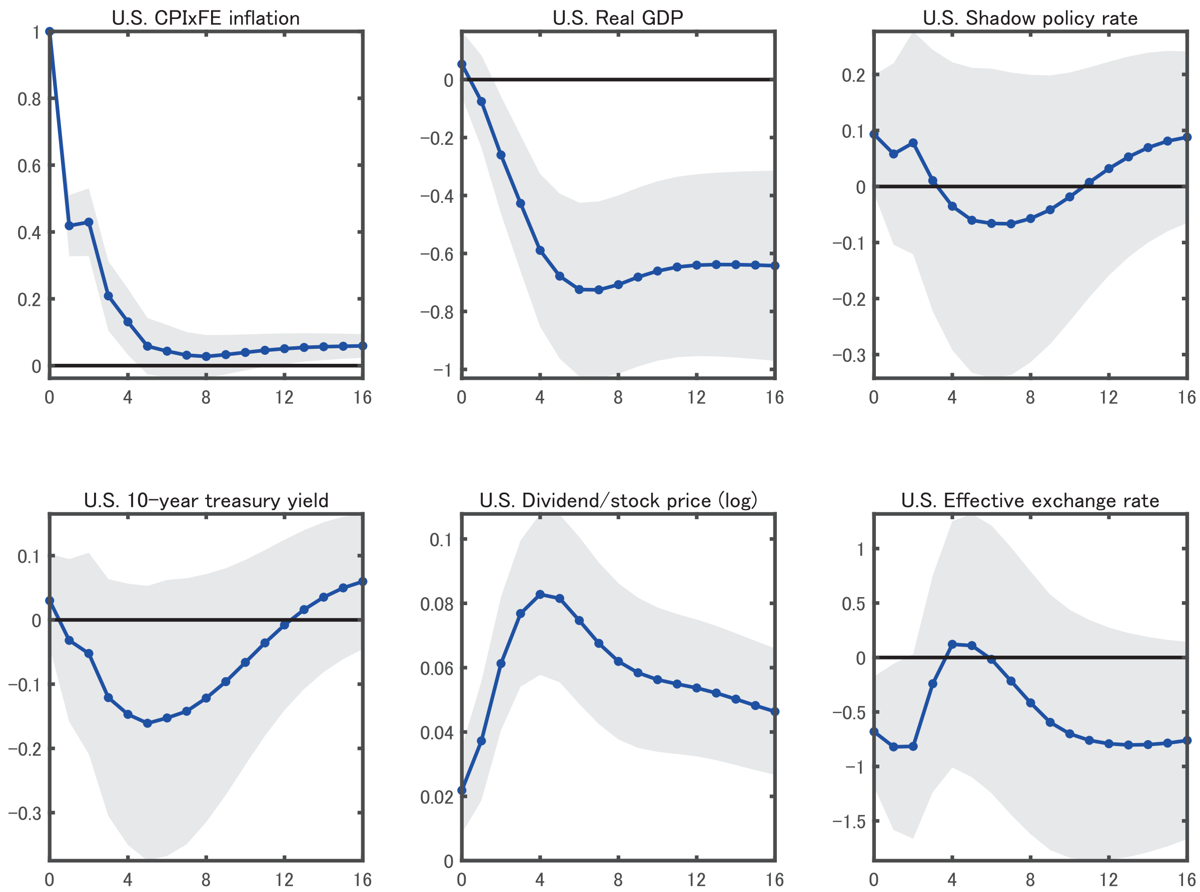

Figure 7: Estimated responses to an unexpected inflationary shock: The case of the U.S.

Notes: The solid line with circles represent the point estimates of the impulse responses to an unexpected inflationary shock. The shaded areas denote one-standard-error bands, calculated using 1000 bootstrap samples. We set the lag length to four quarters in the reduced-form vector autoregressive (VAR) estimation. Estimation samples span from the first quarter of 1983 to the fourth quarter of 2018.

only less than 10% of the forecast error variance of U.S. real GDP 16 quarters ahead, although they have a reasonably high explanatory power in the short-term horizons. This result contrasts with the Japanese case, where inflationary pressure shocks explain a substantial proportion of the variation in real GDP. These findings imply that the different preferences between the BOJ and the Federal Reserve regarding decisiveness for macroeconomic stability would have led to differences in the magnitude of macroeconomic fluctuations due to demand-pull pressures and consequently to differences in business cycles.

Table 3: Share of the forecast error variance explained by unexpected inflation or inflationary pressure shocks for inflation, real output, and financial variables: The case of the U.S.

Variable X_k ($k = 1, \cdots, 6$)	[1]		[2]		[3]		[4]		[5]		[6]	
Shock ϵ^j ($j = c, p$)	ϵ^c	ϵ^p	ϵ^c	ϵ^p	ϵ^c	ϵ^p	ϵ^c	ϵ^p	ϵ^c	ϵ^p	ϵ^c	ϵ^p
Horizon (h)												
0	100	0	0.4	28.0	1.2	59.9	0.2	60.1	4.3	11.1	2.0	0.4
1	93.7	4.8	0.4	24.4	0.6	62.5	0.1	62.4	6.5	11.1	1.8	0.6
4	84.7	12.4	7.6	15.9	0.3	69.4	0.9	66.8	21.8	9.5	1.1	0.6
8	78.7	18.1	15.6	9.9	0.3	64.6	1.6	65.7	29.3	9.5	0.7	1.9
16	73.9	21.6	17.9	6.8	0.4	59.3	1.8	63.4	30.5	17.2	1.4	3.4

[1] U.S. CPIxFE inflation
[2] U.S. Real GDP (log)
[3] U.S. Shadow policy rate
[4] U.S. 10-year treasury yield
[5] U.S. Dividend/stock price (log)
[6] U.S. Effective exchange rate (log)

Notes: The entries are $\Omega_{k,c}(h)$ and $\Omega_{k,p}(h)$ for $k = 1, \cdots, 6$, which show the percentage share of the variance of the forecast error by the variable described in the upper header at a given horizon h as explained by the unexpected inflationary shocks ϵ^c and inflationary pressure shocks ϵ^p, respectively. The results are computed from the vector autoregressive (VAR) model (3) with the restricted optimization problems (10), (11), and (12) over the sample period from the first quarter of 1983 to the fourth quarter of 2018. We set the lag length to four quarters in the reduced-form VAR estimation.

5 Conclusions

In the extant literature, quantitative investigations of the causal relationships among inflation expectations, the macroeconomy, and monetary policy remain scarce. Hence, this study developed a time-series model of inflation dynamics. In particular, we proposed a novel empirical framework to quantify the causal relationships among future inflation, the macroeconomy, and monetary policy. Our framework of a structural VAR model measures inflationary pressures as anticipated shocks to future inflation caused by surprise changes in the VAR variables other than the inflation itself. We employed the structural VAR model to estimate the dynamic causal effects of inflationary pressure shocks on the macroeconomy.

Our empirical results demonstrate that managing inflation forecasts is essential for conducting monetary policy that can achieve the goal of macroeconomic stability. Specifically, identified inflationary pressure shocks qualify as demand-pull factors in inflation dynamics, whereas unexpected inflationary shocks can be characterized as cost-push factors. Inflationary pressure shocks also act as a driving force for stochastic changes in trends in inflation dynamics. Furthermore, inflationary pressure shocks were one of the primary sources of the business cycle during Japan's bubble economy and subsequent prolonged economic slump. Meanwhile, the contribution of inflationary pressures to the business cycle in the U.S, with its relatively stable macroeconomy, is limited. Hence, differences in the macroeconomy can largely explain the differences in the systematic response of monetary policy to inflationary pressures between the U.S. and Japan. These results have implications for central banks in that monitoring of future inflation expectations as well as implementing preemptive and proactive policy are crucial for achieving their goal of macroeconomic stability.

Nevertheless, our study has the following limitation. We did not explore the relationship between the inflation pressures identified in this study and inflation expectations in practice. Moreover, our empirical model does not provide an effective measure of inflation expectations. As partly reviewed in subsection 2.3, previous studies have developed the methodology for measuring inflation expectations in real-time using financial information and surveys.[22] Hence, future research should examine the robustness of our results by analyzing the role of inflation forecasts, as in the methodology of this study, using real-time data on inflation expectations. By identifying inflationary pressures from the inflation expectations of policymakers and market participants, as in Kuttner and Shibamoto (2019), researchers would quantitatively clarify the role of inflation expectations in the macroeconomy in practice.

A Appendix

A.1 Variable definitions

- CPI: Consumer price index for all items excluding fresh foods (2015=100); consumption-tax-adjusted series for the period from April 1997 to March 1998 and April 2014 to March 2015; calculated backward for the period before December 1989 using the monthly change in the index and adding 1.2 in March 1989 to eliminate the influence of the consumption tax from April 1989; retrieved from the Ministry of Internal Affairs and Communications;

[22] However, it is still challenging to measure inflation expectations. In particular, it is difficult to find data on inflation expectations in practice that can be used sufficiently to perform time-series analysis. There are also some issues to be discussed, such as the fact that measures of inflation expectations may include other factors than the inflation expectations of interest and that inflation expectations are different among agents. Nevertheless, Faust and Wright (2013) point out that models that include inflation expectations of policymakers and market participants tend to outperform various other inflation forecasts using time-series modeling.

Seasonally adjusted series were obtained using the Census X-12. quarterly average.

- Real GDP: National accounts statistics compiled according to 1993 SNA and 2008 SNA (benchmark year=2011) from the 1st quarter of 1980 through the 4th quarter of 2018 (Data prior to 1994 using the 1993 SNA series), chain-linked method (1993 SNA and 2008 SNA), seasonally adjusted quarterly series, retrieved from HAVER ANALYTICS (billion yen).

- Shadow policy rate: The uncollateralized overnight call rate (monthly average, %); monthly series retrieved from the Bank of Japan statistics for the period from July 1985 to December 1994 and calculated backward for the period before June 1985 using the monthly change in the collateralized overnight call rate; retrieved from the Bank of Japan statistics. Monthly average shadow short rate series, retrieved from the website Reserve Bank of New Zealand for the period from January 1995 to December 2018. quarterly average.

- 10-year treasury yield: 10-year Japanese government bond yields (end of month, %), retrieved from NIKKEI NEEDS FINANCIAL QUEST. quarterly average.

- Dividend/stock price: Dividend yield (1st Section, average, %), retrieved from NIKKEI NEEDS FINANCIAL QUEST. quarterly average.

- Effective exchange rate: Nominal effective exchange rates by the BIS, 2010 AVERAGE=100 retrieved from NIKKEI NEEDS FINANCIAL QUEST. quarterly average.

- USSPR: The effective federal funds rate retrieved from Federal Reserve Economic Data (FRED), monthly average shadow policy rate series, retrieved from the website Reserve Bank of New Zealand from January 2009 to November 2015. quarterly average.

- USTERM: The spread between the 10-year treasury bond and 3-month treasury bill, retrieved from FRED. quarterly average.

- USTED: The spread between the 3-month LIBOR based on U.S. dollars and 3-month treasury bill retrieved from FRED. quarterly average.

- USVIX: For the period before 1990, Chicago Board of Options Exchange VXO index series, retrieved from the Nicholas Bloom's website. For the period from 1990, Chicago Board Options Exchange Volatility Index, retrieved from FRED. quarterly average.

- POIL: Crude oil prices, West Texas Intermediate (WTI), retrieved from FRED. quarterly average.

- PCOM: The International Monetary Fund (IMF)'s all commodity price index, includes both Fuel and Non-Fuel Price Indices, 2016 = 100. For the period from January 1992 to December 2002, the index is calculated by backward recursion of changes based on the index expressed using a 2010=100 weights reference period. For the periods prior to 1992, the index is calculated by backward recursion of changes based on the previously used indices (00176axd). quarterly average.

- U.S. CPIxFE: Consumer price index for all urban consumers: all items excluding food and energy in U.S. city average, seasonally adjusted series, retrieved from FRED. quarterly average.

- U.S. Real GDP: U.S. Bureau of Economic Analysis, Real Gross Domestic Product, billions of chained 2012 dollars, seasonally adjusted quarterly series, retrieved from FRED.

- U.S. Shadow policy rate: Effective federal funds rate retrieved from FRED, monthly average shadow policy rate series, retrieved from the website of Reserve Bank of New Zealand from January 2009 to November 2015. quarterly average.

- U.S. 10-year treasury yield: The 10-year treasury bond constant maturity yield, retrieved from FRED. quarterly average.

- U.S. Dividend/stock price: S&P 500 dividend yield (12 month dividend per share)/price, retrieved from HAVER ANALYTICS. quarterly average.

- U.S. Effective exchange rate: Nominal effective exchange rates by the BIS, 2010=100, retrieved from BIS. quarterly average.

References

Andreasen, Martin M., Jens H. E. Christensen, and Simon Riddell. 2021. "The TIPS Liquidity Premium." *Review of Finance* 25 (6): 1639–1675.

Ang, Andrew, Jean Boivin, Sen Dong, and Rudy Loo-Kung. 2011. "Monetary Policy Shifts and the Term Structure." *The Review of Economic Studies* 78 (2): 429–457.

Angeletos, George-Marios, Fabrice Collard, and Harris Dellas. 2020. "Business-Cycle Anatomy." *American Economic Review* 110 (10): 3030–3070.

Ascari, Guido, and Argia M. Sbordone. 2014. "The Macroeconomics of Trend Inflation." *Journal of Economic Literature* 52 (3): 679–739.

Barsky, Robert B., and Eric R. Sims. 2011. "News shocks and business cycles." *Journal of Monetary Economics* 58 (3): 273–289.

Ben Zeev, Nadav, Christopher Gunn, and Hashmat Khan. 2020. "Monetary News Shocks." *Journal of Money, Credit and Banking* 52 1793–1820.

Bernanke, Ben S. 2000. "Japanese Monetary Policy: A Case of Self-Induced Paralysis." In *Japan's Financial Crisis and Its Parallels to U.S. Experience*, edited by Mikitani, Ryoichi, and Adam S. Posen 149–166.

Bernanke, Ben S. 2007. "Inflation Expectations and Inflation Forecasting." Speech At the Monetary Economics Workshop of the National Bureau of Economic Research Summer Institute, Cambridge, Massachusett.

Bernanke, Ben S., and Alan S. Blinder. 1992. "The Federal Funds Rate and the Channels of Monetary Transmission." *American Economic Review* 82 (4): 901–921.

Bernanke, Ben S., and Mark Gertler. 1999. "Monetary Policy and Asset Price Volatility." *Federal Reserve Bank of Kansas City, Economic Review* 84 (4): 17–51.

Blanchard, Olivier, Eugenio Cerutti, and Lawrence Summers. 2015. "Inflation and Activity Two Explorations and their Monetary Policy Implications." *IMF Working Papers* 15 (230): .

Blanchard, Olivier Jean, and John Simon. 2001. "The Long and Large Decline in U.S. Output Volatility." *Brookings Papers on Economic Activity* (1): 135–164.

Bloom, Nicholas. 2009. "The Impact of Uncertainty Shocks." *Econometrica* 77 (3): 623–685.

Campbell, Jeffrey R., Charles L. Evans, Jonas D. M. Fisher, and Alejandro Justiniano. 2012. "Macroeconomic Effects of Federal Reserve Forward Guidance." *Brookings Papers on Economic Activity* 43 (1): 1–80.

Campbell, John Y. 1999. "Asset Prices, Consumption, and the Business Cycle." In *Handbook of Macroeconomics*, edited by Taylor, John B., and Michael Woodford Volume 1c. 1231–1303, North Holland.

Canova, Fabio, Luca Gambetti, and Evi Pappa. 2007. "The Structural Dynamics of Output Growth and Inflation: Some International Evidence." *Economic Journal* 117 (3): C167–C191.

Christensen, Jens H. E., Jose A. Lopez, and Glebbi D. Rudebusch. 2010. "Inflation Expectations and Risk Premiums in an Arbitrage-Free Model of Nominal and Real Bond Yields." *Journal of Money, Credit and Banking* 42 (6): 143–178.

Christensen, Jens H. E., Jose A. Lopez, and Glenn D. Rudebusch. 2012. "Extracting Deflation Probability Forecasts from Treasury Yields." *International Journal of Central Banking* 8 (4): 21–60.

Christensen, Jens H. E., and Mark M. Spiegel. forthcoming. "Monetary Reforms and Inflation Expectations in Japan: Evidence from Inflation-indexed Bonds." *Journal of Econometrics* 1–22.

Clarida, Richard, Jordi Gali, and Mark Gertler. 1998. "Monetary Policy Rules in Practice Some International Evidence." *European Economic Review* 42 (6): 1033–1067.

Clarida, Richard, Jordi Gali, and Mark Gertler. 1999. "The Science of Monetary Policy: A New Keynesian Perspective." *Journal of Economic Literature* 37 (4): 1661–1707.

Clarida, Richard, Jordi Gali, and Mark Gertler. 2000. "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory." *Quarterly Journal of Economics* 115 (1): 147–180.

Claus, Edda, and Mardi Dungey. 2012. "U.S. Monetary Policy Surprises: Identification with Shifts and Rotations in the Term Structure." *Journal of Money, Credit and Banking* 44 (7): 1443–1453.

Del Negro, Marco, Michele Lenza, Giorgio E. Primiceri, and Andrea Tambalotti. 2020. "What's Up with the Phillips Curve?" *Brookings Papers on Economic Activity* spring (1): 301–357, No.27003.

Ellingsen, Tore, and Ulf Söderstrom. 2001. "Monetary Policy and Market Interest Rates." *American Economic Review* 91 (5): 1594–1607.

Estrella, Arturo, and Frederic S. Mishkin. 1997. "The Predictive Power of the Term Structure of Interest Rates in Europe and the United States: Implications for the European Central Bank." *European Economic Review* 41 1375–1401.

Faust, Jon. 1998. "The Robustness of Identified VAR Conclusions about Money." *Carnegie-Rochester Conference Series on Public Policy* 49 (1): 207–244.

Faust, Jon, and Jonathan H. Wright. 2013. "Forecasting Inflation." In *Handbook of Economic Forecasting*, edited by Graham Elliott, Allan Timmermann 2–56, volume2-A.

Fisher, Irving. 1926. "A Statistical Relation between Unemployment and Price Changes." *International Labour Review* 13 (6): 785–792.

Francis, Neville, Michael T. Owyang, Jennifer E. Roush, and Riccardo DiCecio. 2014. "A Flexible Finite-horizon Alternative to Long-run Restrictions with an Application to Technology Shock." *Review of Economics and Statistics* 96 (4): 638–647.

Friedman, Benjamin M., and Kenneth N. Kuttner. 1993. "Another Look at the Evidence on Money-Income Causality." *Journal of Econometrics* 57 189–203.

Gordon, Robert J. 1997. "The Time-Varying NAIRU and its Implications for Economic Policy." *Journal of Economic Perspectives* 11 11–32.

Hamilton, James D. 1992. "Was the Deflation during the Great Depression Anticipated? Evidence from the Commodity Futures Market." *American Economic Review* 82 (1): 157–78.

Hamilton, James D. 1994. *Time Series Analysis.* Princeton: Princeton University Press.

Hazell, Jonathon, Juan Herreño, Emi Nakamura, and Jón Steinsson. forthcoming. "The Slope of the Phillips Curve: Evidence from U.S. States." *Quarterly Journal of Economics.*

Hiraki, Kazuhiro, and Wataru Hirata. 2020. "Market-based Long-term Inflation Expectations in Japan: A Refinement on Breakeven Inflation Rates." *Bank of Japan Working Paper Series*, No.20-E-5.

Hooper, Peter, Frederic S. Mishkin, and Amir Suf. 2020. "Prospects for Inflation in a High Pressure Economy: Is the Phillips Curve Dead or Is It Just Hibernating?" *Research in Economics* 74 26–62.

Jinushi, Toshiki, Yoshihiro Kuroki, and Ryuzo Miyao. 2000. "Monetary Policy in Japan Since the Late 1980s: Delayed Policy Actions and Some Explanations." In *Japan's Financial Crisis and Its Parallels to U.S. Experience*, edited by Mikitani, Ryoichi, and Adam Posen, Washington D.C.: Peterson Institute for International Economics.

Kaihatsu, Sohei, and Jouchi Nakajima. 2018. "Has Trend Inflation Shifted?: An Empirical Analysis with An Equally-Spaced Regime-Switching Model." *Economic Analysis and Policy* 59 69–83.

Kurmann, André, and Christopher Otrok. 2013. "News Shocks and the Slope of the Term Structure of Interest Rates." *American Economic Review* 103 (6): 2612–2632.

Kuttner, Kenneth N. 2004. "The Role of Policy Rules in Inflation Targeting." *Federal Reserve Bank of St. Louis Review* 86 (4): 89–111.

Kuttner, Kenneth N. 2014. "Monetary Policy During Japan's Great Recession: From Self-Induced Paralysis to Rooseveltian Resolve." In *Lessons from Decades Lost: Economic Challenges and Opportunities Facing Japan and the United States*, edited by Hanyu, Jiro, and Adam S. Posen 66–80.

Kuttner, Kenneth N., and Masahiko Shibamoto. 2019. "Inflation Pressure." *mimeo.*

Mankiw, N. Gregory, and Ricardo Reis. 2002. "Sticky Information Versus Sticky Prices: A Proposal To Replace The New Keynesian Phillips Curve." *Quarterly Journal of Economics* 117 (4): 1295–1328.

McCarthy, Jonathan. 2007. "Pass-through of Exchange Rates and Import Prices to Domestic Inflation in Some Industrialized Economies." *Eastern Economic Journal* 33 (4): 511–537.

Nakamura, Emi, and Jón Steinsson. 2018. "High Frequency Identification of Monetary Non-Neutrality: The Information Effect." *Quarterly Journal of Economics* 133 1283–1330.

Okimoto, Tatsuyoshi. 2019. "Trend Inflation and Monetary Policy Regimes in Japan." *Journal of International Money and Finance* 92 137–152.

Phillips, A. W. 1958. "The Relation Between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861-1957." *Economica* 25 (100): 283–299.

Ramey, Valerie A. 2016. "Macroeconomic Shocks and Their Propagation." In *Handbook of Macroeconomics Volume.2*, edited by Taylor, John B., and Harald Uhlig 71–162, Amsterdam: Elsevier.

Romer, Christina D., and David H. Romer. 2000. "Federal Reserve Information and the Behavior of Interest Rates." *American Economic Review* 90 (3): 429–457.

Shibamoto, Masahiko. 2008. "The Estimation of Monetary Policy Reaction Function in a Data-Rich Environment: The Case of Japan." *Japan and the World Economy* 20 (4): 497–520.

Shibamoto, Masahiko. 2022. "Cyclical Activity and Inflation under Secular Stagnation: Empirical Evidence Using Data on Japan's Lost Decades." *RIEB Discussion Papers*, DP2022-32.

Shibamoto, Masahiko, and Masato Shizume. 2014. "Exchange Rate Adjustment, Monetary Policy and Fiscal Stimulus in Japan's Escape from the Great Depression." *Explorations in Economic History* 53 1–18.

Simon, John, Troy Matheson, and Damiano Sandri. 2013. "The Dog That Didn't Bark: Has Inflation Been Muzzled or Was It Just Sleeping?" World Economic Outlook: Hopes, Realities, Risks, Washington: International Monetary Fund.

Sims, Christopher A. 1980. “Macroeconomics and Reality.” *Econometrica* 48 (1): 1–48.

Sims, Christopher A. 1992. “Interpreting the Macroeconomic Time Series Facts : The Effects of Monetary Policy.” *European Economic Review* 36 (5): 975–1000.

Sims, Christopher A. 2003. “Implications of Rational Inattention.” *Journal of Monetary Economics* 50 665–690.

Sims, Christopher A., James H. Stock, and Mark W. Watson. 1990. “Inference in Linear Time Series Models with Some Unit Roots.” *Econometrica* 58 (1): 113–44.

Stock, James H., and Mark W. Watson. 2003. “Forecasting Output and Inflation: The Role of Asset Prices.” *Journal of Economic Literature* 41 (3): 788–829.

Stock, James H., and Mark W. Watson. 2005. “Understanding Changes in International Business Cycle Dynamics.” *Journal of the European Economic Association* 3 (5): 968–1006.

Stock, James H., and Mark W. Watson. 2007. “Why Has Inflation Become Harder to Forecast?” *Journal of Money, Credit and Banking* 39 (1): 3–34.

Stock, James H., and Mark W. Watson. 2016. “Factor Models and Structural Vector Autoregressions in Macroeconomics.” In *Handbook of Macroeconomics Volume.2*, edited by Taylor, John B., and Harald Uhlig 415–526, Amsterdam: Elsevier.

Svensson, Lars E. O. 1997. “Inflation Forecast Targeting: Implementing and Monitoring Inflation Targets.” *European Economic Review* 41 (6): 1111–1146.

Taylor, John B. 1993. “Discretion Versus Policy Rules in Practice.” *Carnegie-Rochester Conference Series on Public Policy* 39 195–214.

Uhlig, Harald. 2004. “Do Technology Shocks Lead to a Fall in Total Hours Worked?.” *Journal of the European Economic Association* 2 (2-3): 361–371.

Watson, Mark W. 2014. “Inflation Persistence, the NAIRU, and the Great Recession.” *American Economic Review* 104 (5): 31–36.

White, Halbert. 1980. “A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity.” *Econometrica* 48 (4): 817–838.