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Quantifying Forward Guidance and Yield Curve Control

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Abstract: This study evaluates the effectiveness of Japan's unconventional monetary policies over the past quarter century within a unified term structure framework. It specifically examines the impact of the Bank of Japan's (BOJ) outcome-based forward guidance and yield curve control (YCC) and incorporates other policy types into the framework. The findings show that the BOJ's forward guidance and YCC have both had a significant impact on the shadow rate. Forward guidance accounted for most of the policy impact in the early stages of unconventional monetary policies and remained influential throughout. YCC, since its introduction in 2016 until March 2022, contributed to more than a third of the policy impact. Furthermore, these policies have been effective in raising output and inflation.

JEL classification: E43, E44, E52, E58

Key words: forward guidance, effective lower bound (ELB), liftoff, term structure, shadow rate, macro finance, unspanned macro factors, yield curve control, Japan

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1 Introduction

Quantifying various unconventional monetary policies in a single framework is difficult primarily due to issues related to the effective lower bound (ELB) and the necessity for consistent metrics across policies. This paper attempts to quantify the effect of several unconventional monetary policies within a unified term structure framework. It focuses on Japan, as the country has employed a range of unconventional monetary policy strategies for the past quarter century.

Our analysis builds on the macro-finance shadow rate term structure model (MF-SRTSM) framework developed by Koeda and Wei (2023). This framework involves explicit modeling of outcome-based forward guidance and is, therefore, particularly relevant to Japan; the Bank of Japan (BOJ) has imposed an inflation-based liftoff condition since it first introduced a zero interest rate policy in 1999.

We assess various unconventional monetary policies by focusing on the divergence in comparable shadow rates. It is useful to investigate the difference rather than the level of shadow rates because it is not easy to completely isolate shocks (other than monetary policy) that directly influence the shadow rate. We investigate unconventional monetary policies by type: forward guidance, yield curve control (YCC), negative interest rate policy (NIRP), and asset purchases.

We find that explicitly accounting for the forward guidance in the MF-SRTSM pushes up the shadow rate and makes it less "shadowy" than the model, referred to as "MF-SRTSM0"; the latter ignores the outcome-based forward guidance but is otherwise identical to the MF-SRTSM. Specifically, our estimation results suggest that, on average, the MF-SRTSM shadow rate lies above the MF-SRTSM0 shadow rate for 69%, 36%, and 23% of the latter rate during the periods of the BOJ's zero-interest rate policy (1999Q1-2000Q2), the first quantitative easing (2001Q1-2006Q1), and the BOJ's quantitative and qualitative monetary easing (QQE; 2013Q1 to the present), respectively. These results show that the impact of forward guidance is significant, especially during the initial phase of unconventional monetary policies.

Turning to YCC, we construct the hypothetical yields that could have emerged if YCC had not been implemented. We then use these yields to re-calculate the model-implied shadow rate. The re-computed MF-SRTSM shadow rate is shallower than the original shadow rate, and we attribute the difference to the YCC effect. We find that, on average, YCC lowered the shadow rate by 161 basis points during 2016Q4 and 2022Q1; this effect accounted for over a third of the overall policy impact during this period, but has diminished since March 2022.

Lastly, we assess the macroeconomic effect of unconventional monetary policies using the factor augmented vector autoregression (FAVAR) model developed by Bernanke et al. (2005), following the methodology in Wu and Xia (2016) and Koeda and Wei (2023). Our analysis allows us to decompose the overall macroeconomic effect of unconventional policies by type. We find that both forward guidance and YCC had significant macroeconomic impact in the investigated period. We find that in the absence of forward guidance, the unemployment rate would have been about 1.2 percentage points higher, and the stock price would have been 48% lower five years after QQE's implementation in April 2013. Conversely, in the absence of YCC, the shadow rate would have been 1.6% shallower, the stock price would have been 21% lower, and the unemployment rate would have been 0.4 percentage points higher four years after the implementation of YCC in September 2016.

This paper is related to several strands of literature. First, it is closely related to term structure literature as Koeda and Wei (2023) combine two types of canonical term structure models: a shadow rate term structure model (Krippner, 2013; Wu and Xia, 2016) and a macro-finance Gaussian term structure model (Joslin et al., 2014; Wright, 2011). Various shadow rate term structure models of Black (1995) type have been applied to Japan, for example by, Kim and Singleton (2012), Christensen and Rudebusch (2015), Ichiue and Ueno (2015), and Imakubo and Nakajima (2015). With the exception of Bauer and Rudebusch (2016) and Akkaya et al. (2015) applied to the United States, the very few previous studies have used a shadow-rate term structure model with observable macroeconomic factors, which is particularly useful during periods where the ELB binds.[1]

Few studies examine the forward guidance effect on bond yield and risk using a term structure framework. Our model is closely related to that of Akkaya et al. (2015) who proposed a term structure model with three factors: two macro factors (unemployment and inflation) and one latent factor. Our study differs from theirs along several important dimensions. First, our model features unspanned macro factors. By contrast, Akkaya et al. (2015) assume that the shadow rate follows a Taylor rule with a monetary policy shock treated as the latent factor. As a result the macro variables are almost fully spanned by bond yields. Second, our framework, which builds upon the shadow rate framework in Black (1995) and Wu and Xia (2016), allows for a closed-form (approximate) solution for forward rates and can be estimated using the maximum likelihood method. Third, our study quantifies different types of policy effects in a unified framework. As noted above, we explicitly model outcome-based forward guidance, rather than defining forward guidance as monetary policy shocks that keep the shadow rate at or below the ELB for a pre-specified period.

[1] Oda and Ueda (2007) and Koeda (2013) also attempt to incorporate macro variables in a term structure framework to study the Japanese case. These models are not formally shadow rate term structure models.

Our study is also related to a relatively large literature on the macroeconomic effect of unconventional policies in Japan.[2] While this study explicitly models forward guidance in a term structure framework, the effectiveness of forward guidance has been frequently discussed in a dynamic stochastic general equilibrium framework (e.g., Gertler (2017) and Katagiri (2016)) or via high-frequency identification (e.g., Kubota and Shintani (2023)).

This study's main contribution is its use of a comprehensive framework to assess and quantify the effectiveness of various types of unconventional monetary policies in Japan. It reveals that the BOJ's outcome-based forward guidance constitutes a substantial part of these unconventional monetary policy measures, as reflected by the shadow rate. Initiated under the leadership of former Governor Kuroda in April 2013, the QQE policy significantly lowered the shadow rate, largely due to the impact of asset purchases. The introduction of YCC into the QQE framework in September 2016 enhanced these effects, with YCC alone contributing over a third of the total policy impact until at least March 2022. Additionally, we find that these unconventional monetary policies effectively increased output and inflation.

The remainder of this study is organized as follows. Section 2 discusses unconventional monetary policies in Japan. Section 3 discusses how to identify each unconventional policy effects in our term structure framework. Section 4 presents estimation results. Section 5 discusses macroeconomic effects. Section 6 concludes.

2 Unconventional monetary policies in Japan

In this section, we summarize the BOJ's unconventional monetary policies for the past quarter century. We discuss these policies by type: forward guidance, YCC, NIRP, and asset purchases.

2.1 Forward guidance

The BOJ's policy at the ELB has consistently focused on a specific inflation condition for policy liftoff since its introduction of the zero interest rate policy in 1999. On April 13, 1999, the BOJ governor committed to maintaining the zero-interest-rate policy "*until the deflationary concerns are dispelled.*" Subsequently, BOJ policy statements have continuously

[2] For further context, refer to summaries by Ugai (2006), Ueda (2012), and Ito and Hoshi (2020). Existing empirical studies on Japan often termed the forward guidance impact as the 'policy duration effect', as seen in Fujiki et al. (2001). The macroeconomic consequences of Japan's unconventional monetary policies have frequently been examined through vector autoregressive (VAR) models. For a recent concise summary of such studies on BOJ policy effectiveness, see e.g., Kubota and Shintani (2023).

emphasized an exit condition based on inflation metrics. On March 19, 2001, the BOJ declared it would maintain this policy "*until the consumer price index (excluding perishables, based on nationwide statistics) consistently shows a 0% or higher year-on-year increase.*" Over time, the BOJ has incrementally raised the bar for its inflation liftoff condition. On December 18, 2009, the BOJ stated that the "*Board does not tolerate a year-on-year rate of change in the CPI equal to or below 0%,*" and on February 14, 2012, that it would maintain its policy "*until it judges that the 1% goal is in sight.*" Most recently, on April 4, 2013, the BOJ aimed "*to achieve the price stability target of 2%, as long as it is necessary to maintain that target in a stable manner.*" Table 1 lists BOJ's statements on its outcome-based forward guidance.

2.2 Negative interest rate

On October 31, 2008, the BOJ established the Complementary Deposit Facility to pay interest on excess reserves (IOER). On December 19 of that same year, it set the interest rate for this facility at 0.1%. On January 29, 2016, the BOJ added a NIRP to its QQE framework, announcing that a negative interest rate of minus 0.1% would be effective from February 16, 2016. Specifically, the BOJ implemented a three-tier system in which a negative rate is applied to the policy rate balance. In short, the BOJ effectively reduced the IOER from 0.1% to -0.1% on February 16, 2016. The IOER is typically regarded as the lower bound of the interest rate corridor. Table 2 lists BOJ's statements related to IOER.

2.3 Yield curve control (YCC)

On September 21, 2016, the BOJ added YCC to its QQE framework following a "Comprehensive Assessment" released the same day. The BOJ maintained its outcome-based forward guidance and NIRP alongside YCC. As Koeda and Ueno (2022) discuss, YCC is a policy that targets or caps one or more specific yields.[3], and it involves both announcement and purchase effects. The announcement effect was suggested by former Fed chairman Bernanke after the BOJ announced its introduction of YCC, expressing his view that the BOJ would be able to meet its yield target by purchasing considerably less than 80 trillion yen of JGBs a year, the target quantity for JGB purchases at that time (Bernanke (2016)). As a result, BOJ purchases had been contained, leading to slower growth in its bond holdings over the several years following the YCC implementation (Figure 1). The announcement effect

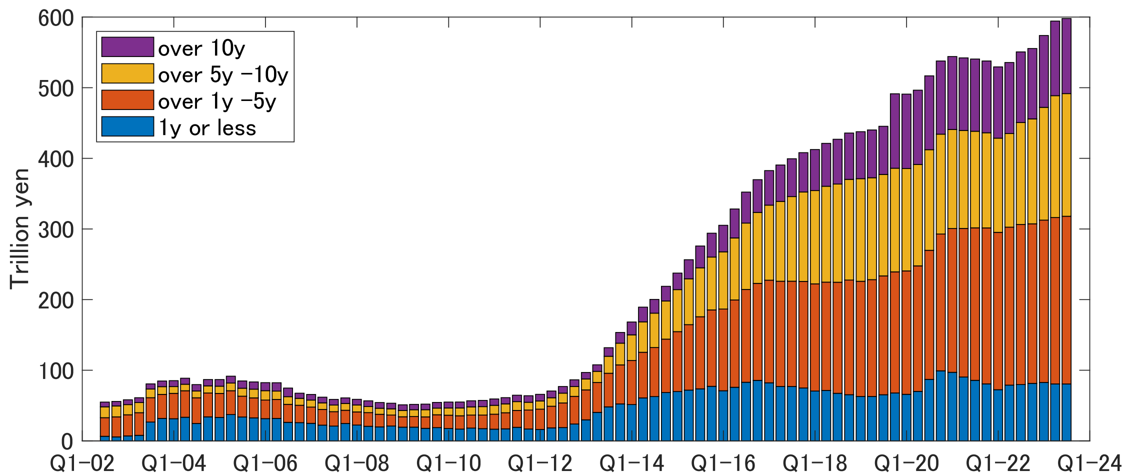
[3] It has been implemented by the Federal Reserve capping yields across the yield curve during and post-WWII, and the Reserve Bank of Australia setting a target for the yield on 3-year Australian government bonds from March 2020 to November 2021.

could weaken if market participants expect YCC to end. On March 19, 2021, based on its "Assessment for Further Effective and Sustainable Monetary Easing,"[4] the BOJ introduced fixed-rate purchase operations for consecutive days, a powerful tool to set an upper limit on interest rates when necessary. Since March 2022, the BOJ conducted large consecutive purchases under these fixed rate operations to sustain YCC. Table 3 lists BOJ's statements related to YCC.

2.4 Asset purchases

Figure 1 shows BOJ's JGB holding by maturity. In the initial stages of unconventional monetary easing, the BOJ's bond holdings with a remaining maturity of over five years were relatively limited. Since the inception of QQE under the leadership of former Governor Kuroda in April 2013, however, there has been a significant expansion in the BOJ's balance sheet.

FIGURE 1: Japanese government bonds and bills held by BOJ



NOTE: Data source: BOJ

In addition to purchasing government bonds, the BOJ has been acquiring other types of assets, including Exchange-Traded Funds (ETFs), commercial papers (CP), and corporate bonds;[5] the BOJ established an asset purchase program encompassing these types of assets when it began its comprehensive monetary easing in October 2010. The implementation of QQE saw intensified purchasing of ETFs to stimulate the economy.

[4]The official document is downloadable at `https://www.boj.or.jp/en/mopo/mpmdeci/mpr_2021/k210319c.pdf`.

[5]See e.g., Aoki (2023) and Shiratsuka (2009) on the composition of the BOJ balance sheet.

3 Macro-Finance Shadow-Rate Term Structure Model: Identifying Policy Effects in Japan

Next, we assess various unconventional monetary policies in Japan using the (*MF-SRTSM*) framework in Koeda and Wei (2023), which extends standard shadow rate term structure models (SRTSM) along two important dimensions. First, it includes key macroeconomic factors, namely, GDP growth and inflation, which are "unspanned" by yield curve factors (Joslin et al., 2014). Second, the extended MF-SRTSM framework incorporates outcome-based forward guidance, which is modeled by two prerequisites for policy commencement: (i) the shadow rate must exceed the ELB, denoted as $\underline{r}$, and (ii) a combined measure of inflation and output must surpass a predefined level, denoted as $\underline{m}$.

In the MF-SRTSM, there exists n_X latent yield curve factors X_t and n_M observable macro factors M_t. Let $Z_t = (X_t', M_t')'$ be the $n_Z \times 1$ vector of state variables with $n_Z = n_X + n_M$.

The state vector Z_t follows the Ornstein–Uhlenbeck process under the physical measure $\mathbb{P}$,

$$dZ_t = \kappa \left(\theta - Z_t\right) dt + \sigma dW_t, \tag{1}$$

where θ is a $n_Z \times 1$ vector representing the long-run level of Z_t, κ as an $n_Z \times n_Z$ matrix governs the rate of mean reversion, σ is a constant $n_Z \times n_Z$ diffusion matrix, and dW_t is a n_Z-dimensional Wiener process. We partition these with respect to the bond and macro factors accordingly.

The market prices of risk are linear with respect to the state variables,

$$\Lambda_t = \Gamma_0 + \Gamma_1 Z_t. \tag{2}$$

The resulting risk-adjusted process for Z_t under the risk-neutral measure $\mathbb{Q}$ is given by

$$dZ_t = \kappa^* \left(\theta^* - Z_t\right) dt + \sigma dW_t^*, \tag{3}$$

where $\kappa^* = \kappa + \sigma\Gamma_1$ and $\theta^* = \kappa^{*-1}\left(\kappa\theta - \sigma\Gamma_0\right)$. The parameters κ^* and θ^* and the Wiener process dW_t^* have the same partition as their measure-$\mathbb{P}$ counterparts.

In the presence of outcome-based forward guidance, a liftoff is not triggered until $s_t \geq \underline{r}$ and $m_t \geq \underline{m}$, aligned with Hayashi and Koeda (2019); that is,

$$r_t = \underline{r}\mathbf{1}_{\{m_t < \underline{m}\}} + \max\left(\underline{r}, s_t\right) \mathbf{1}_{\{m_t \geq \underline{m}\}}, \tag{4}$$

where $m_t \equiv \delta_2' M_t$ represents a weighted macro index with weights δ_2, s_t denotes the shadow rate that is an affine function of the state variables

$$s_t = \delta_0 + \delta_1' Z_t = \delta_0 + \delta_{1,1}' X_t + \delta_{1,2}' M_t, \tag{5}$$

and $\mathbf{1}_{\{\cdot\}}$ is an indicator function that takes a value of one if the condition in the curly brackets is true, and zero otherwise.

Following Joslin et al. (2014) and Wright (2011), the macro factors are assumed to be "unspanned." Specifically, we assume an autonomous process for the bond yield factors X_t under measure $\mathbb{Q}$ (i.e., the upper-right block of κ^* is zero) and the shadow rate does not directly depend on M_t (i.e., the last n_M elements of δ_1, or $\delta_{1,2}$, are zero). That is,

$$\kappa_{12}^* = 0, \tag{6}$$
$$\delta_{1,2} = 0. \tag{7}$$

Moreover, by applying Proposition 1 in Joslin et al. (2011) to the latent bond factors X_t, we can focus on the canonical representation where κ_{11}^* is in ordered real Jordan form, $\sigma_{12} = 0$, $\theta_1^* = 0$, and $\delta_{1,1} = \iota$ is a $n_X \times 1$ vector of ones.

Koeda and Wei (2023) derive an analytical approximation for the forward rate in MF-SRTSM, which we borrow and repeat in the following proposition (see Koeda and Wei (2023) for detailed derivations).

Proposition 1. *In MF-SRTSM, the instantaneous forward rate can be approximated by*

$$f_{t,\tau}^{MFSRTSM} = \underline{r} + \sigma_\tau^{\mathbb{Q}} g\left(\frac{a_\tau + b_\tau' X_t - \underline{r}}{\sigma_\tau^{\mathbb{Q}}}, \frac{c_\tau + d_\tau' M_t + e_\tau' X_t - \underline{m}}{\eta_\tau^{\mathbb{Q}}}; \varrho_\tau^{\mathbb{Q}}\right), \tag{8}$$

where

$$\begin{aligned}
g(z_1, z_2; \varrho) &\equiv h(-z_1, -z_2; \varrho) + \varrho h(-z_2, -z_1; \varrho) + z_1 F(z_1, z_2; \varrho), \\
h(z_1, z_2; \varrho) &\equiv \phi(z_1)\, \Phi\left(\frac{\varrho z_1 - z_2}{\sqrt{1-\varrho^2}}\right), \\
F(z_1, z_2; \varrho) &= \int_{-\infty}^{z_1}\int_{-\infty}^{z_2} \frac{1}{2\pi\sqrt{1-\varrho^2}} \exp\left\{-\frac{z_1^2 - 2\varrho z_1 z_2 + z_2^2}{2(1-\varrho^2)}\right\},
\end{aligned}$$

and the expressions for the coefficients c_τ, d_τ, e_τ, $\sigma_\tau^{\mathbb{Q}}$, $\eta_\tau^{\mathbb{Q}}$ and $\varrho_\tau^{\mathbb{Q}}$ are provided in Equations (B-3a-c) and (B-2a-c) in the Appendix.

The approximation in Equation (8) is a natural extension of the approximation in SRTSMs, as in Krippner (2013) and Wu and Xia (2016). The forward rate $f_{t,\tau}^{MFSRTSM}$ now depends not only on $\left(\frac{a_\tau + b_\tau' X_t - \underline{r}}{\sigma_\tau^{\mathbb{Q}}}\right)$, a measure of the distance of the shadow rate from the bound $\underline{r}$, but also on $\left(\frac{c_\tau + d_\tau' M_t + e_\tau' X_t - \underline{m}}{\eta_\tau^{\mathbb{Q}}}\right)$, a measure of the distance of the macro index from the bound $\underline{m}$. As a result, the forward rate is now approximated by a bivariate function.

The extension is intuitive because the timing of liftoff in the MF-SRTSM is now influenced by the yield curve *and* macro factors. In the extreme case where the macro threshold $\underline{m}$ is sufficiently low, the approximation in Equation (8) coincides with the approximation in SRTSMs, such as those in Krippner (2013) and Wu and Xia (2016).

The Stance of Forward Guidance. Koeda and Wei (2023) develop a macro-finance shadow-rate model to single out the effect of forward guidance. This model, referred to here as "MF-SRTSM0", is almost identical to MF-SRTSM, except that there is no outcome-based forward guidance. The authors demonstrate that the forward rate approximation in the simplified MF-SRTSM0 is the same as in the SRTSMs in Krippner (2013) and Wu and Xia (2016).

Koeda and Wei (2023) also show that incorporating outcome-based forward guidance in the MF-SRTSM pushes the shadow rate higher than the level in MF-SRTSM0. The higher shadow rate in MF-SRTSM obtains because, all else being equal, the presence of the outcome-based forward guidance makes it harder to satisfy the liftoff conditions, giving rise to a relatively lower shadow rate in MF-SRTSM0 that ignores the forward guidance. Put differently, explicitly accounting for the forward guidance in MF-SRTSM helps make the shadow rate less "shadowy" since we are able to single out the effect of the forward guidance.

Therefore, we use the difference between the shadow rates in the MF-SRTSM and MF-SRTSM0 to measure the effectiveness of outcome-based forward guidance as proposed in Koeda and Wei (2023).

The Stance of YCC. We address the challenges of quantifying both the announcement and purchase effects of YCC by adopting a method akin to the backcasting exercise in Gürkaynak et al. (2008). Specifically, we construct hypothetical yields using the relationship among nominal and real bond yields, and expected inflation derived from a subsample estimation for the period 1990 to 2015, prior to the implementation of YCC. The real bond yield is measured by inflation-indexed JGB (JGBi) yield, and expected inflation is measured by the ESP forecast, a professional forecast conducted by the Japan Center for Economic Research. The methodology is detailed in Appendix A. In principle, the relationship among the nominal and real bond yields and expected inflation should be stable; however, it may be affected by YCC imposing extra downward pressure on nominal interest rates.

Using the hypothetical yields, we re-compute the shadow rate under MF-SRTSM (termed "hMF-SRTSM" where "h" stands for hypothetical) using the sub-sample parameter estimates. The difference between the hMF-SRTSM and MF-SRTSM shadow rates captures the YCC effects.

Lastly, the impact of asset purchases can be captured by the unexplained part of the shadow rate. This effect corresponds to the difference between the ELB and the MF-SRTSM shadow rate prior to the introduction of NIRP in early 2016. After the September 2016 introduction of YCC, the effect is captured by the difference between the ELB and the hMF-SRTSM shadow rate. We do not differentiate effects by asset type.

4 Estimation and Results

4.1 Data

In this section, we provide a brief summary of the data used for our estimation and then discuss the estimated results.

Our estimations cover the whole sample period of 1990Q1 and 2023Q2 and a subsample period of 1990Q1 and 2015Q4. The one quarter-ahead forward rates are computed using zero coupon bond yields obtained from Bloomberg.[6] We use forward rates in the 1-, 2-, 4-, 8-, 20-, 28-, and 40-quarter maturities as in Wu and Xia (2016) for estimation. Figure 2 plots the historical forward rates in our sample period.

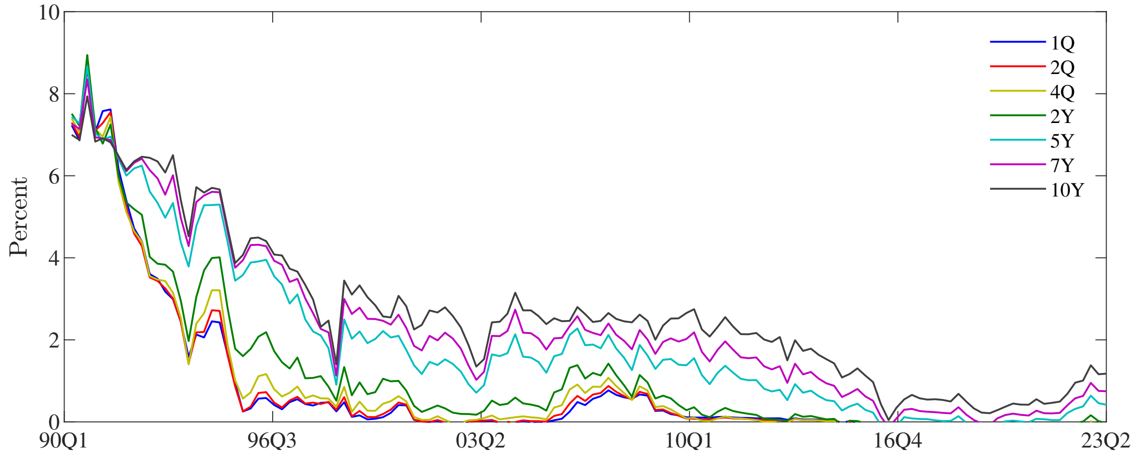
For unspanned macro factors, we use the real GDP growth rate, which represents the change from the same quarter of the previous year. This data is from the Cabinet Office of Japan's quarterly estimates as of September 8, 2023 (the second preliminary version), with 2015 as the base year. The inflation series represents the Consumer Price Index (the change from the same quarter of the previous year) and uses 2020 as the base year, as provided by the Ministry of Internal Affairs and Communications. Figure 3 plots these variables for our sample period.

The inflation expectation is measured with the ESP Forecast, a monthly professional forecast survey on the Japanese economy conducted by the Japan Center for Economic Research. The survey collects predictions from around 40 experts on Japan's macroeconomic and financial indicators for the current and next fiscal year. For inflation, they forecast the year-on-year changes in the Consume Price Index (CPI), excluding fresh foods.[7]

[6] The Bloomberg bond yields are provided in 1-, 2-, 4-, 8-, 12-, 16-, 20-, 24-, 28-, 32-, 36-, 40-, 60-, 80-, 120-quarter maturities. We apply Nelson-Siegel curves to obtain bond yields at every quarterly maturity from 1- to 120-quarters.

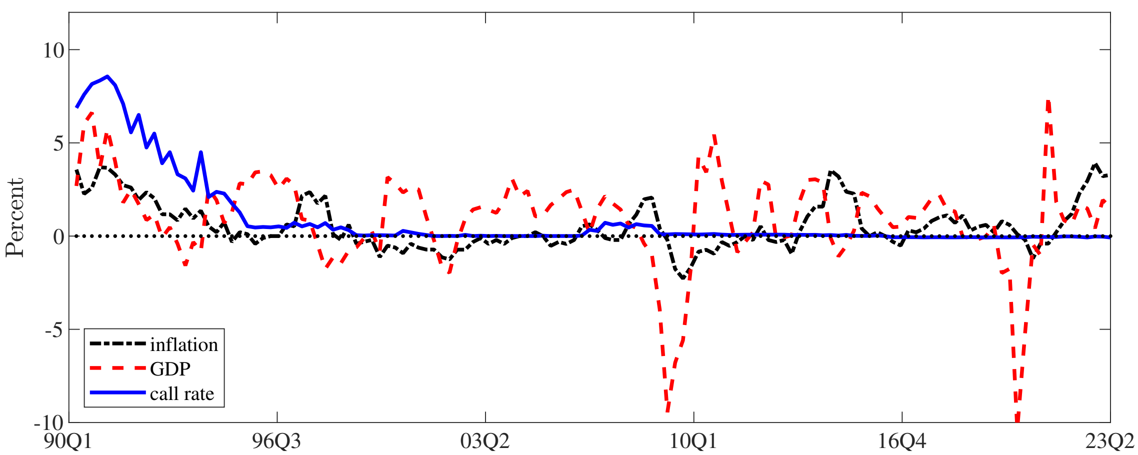
[7] See Nakazono (2016) and Adachi and Hiraki (2021) for a comparison of existing inflation expectation

FIGURE 2: Forward rates



NOTE: This figure plots one-quarter ahead forward rates as described in Section4.1.

FIGURE 3: Macro factors and policy rate



NOTE: This figure plots the policy rate known as the uncollateralized overnight call rate (blue solid line), GDP growth (black dash-dotted line), and CPI inflation (red dashed line).

We set $\underline{m}$ and $\underline{r}$ following BOJ's policy announcements referenced in Appendix Tables 1 and 2. We set an exogenous path for $\underline{m}$ allowing it to depend on the announced inflation conditions alone: at 0% between 1990Q2 and 2011Q4, at 1% between 2012Q1 and 2012Q4, and at 2% from the first quarter of 2013 onward. Prior to the introduction of the zero-interest rate policy between 1990Q1 and 1999Q1, $\underline{m}$ is set at a very negative number (-10%). Based on the IOER, we set $\overline{r}$ at 0% up to the third quarter of 2008, increase it to 0.1% from the

measures.

fourth quarter of 2008, and then reduce it to -0.1% from the first quarter of 2016 onwards. We address NIRP in the alteration of $\overline{r}$.[8]

4.2 Estimated parameters

As in Koeda and Wei (2023), we estimate each model using the maximum likelihood method. In addition to the MF-SRTSM0 and MF-SRTSM, we estimate the canonical shadow rate term structure model without macro factors (denoted as "SRTSM") and macro-finance Gaussian term structure model without the ELB (denoted as "MF-GTSM"). Details on these models can be found in Koeda and Wei (2023).

We provide the coefficient estimates for the MF-SRTSM0, MF-SRTSM, SRTSM, and MF-GTSM in Tables 4- 7 for the subsample and Tables 8- 11 for the whole sample. Notably, all eigenvalues of ρ^Q and ρ_Z are less than 1 in absolute value, with the sole exception of ρ_Z in the MF-GTSM when the ELB is not considered for the whole sample estimation.

Tables 4- 7. Japan: Estimated Parameters: 1990Q1-2015Q4

Tables 8- 11. Japan: Estimated Parameters: 1990Q1-2023Q2

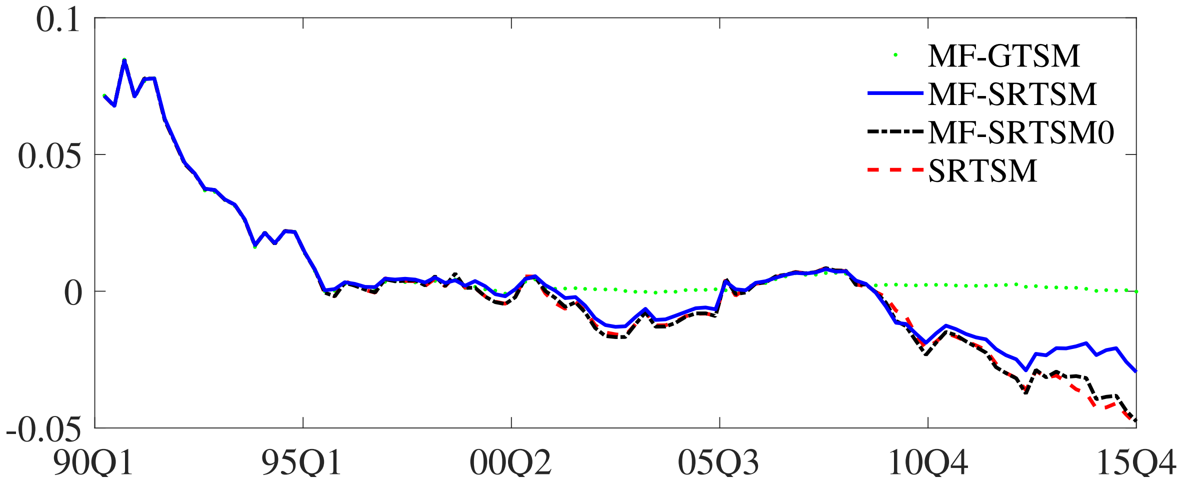
As the MF-SRTSM nests the MF-SRTSM0 when $\underline{m}$ is estimated as an additional parameter, we can conduct a likelihood ratio test setting $\underline{m}$ as equal to a very negative number under the null hypothesis (e.g., $H_0 : \underline{m} = -10\%$). Under the alternative hypothesis, $\underline{m}$ equals to the estimated value. The test statistic for the subsample estimation results is significantly large, leading to the rejection of the MF-SRTSM0 in favor of the MF-SRTSM at the 1% significance level. With the inclusion of YCC and NIRP periods, however, the MF-GTSM attains the highest fit to the data.

4.3 Shadow rates

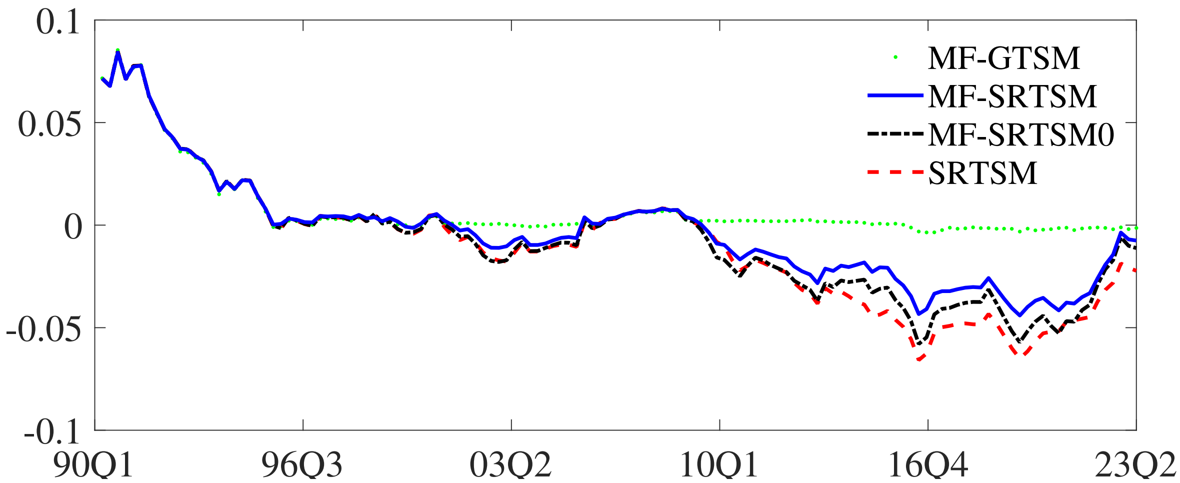
Figure 4 depicts the shadow rates implied by various models for the subsample period ending prior to the implementation of NIRP and YCC (upper panel, 1990-2015) and for the whole sample period (lower panel, 1990-2023Q2). The SRTSM shadow rate (red dashed line) reaches as low as -5% during the ELB periods, while it largely coincides with the observed policy rate in the non-ELB periods. The short rate in the absence of ELB (green dotted line, MF-GTSM) approaches the lower bound during the ELB periods. Consistent with the US results discussed by Koeda and Wei (2023), incorporating macro factors helps mitigate

[8] Fatum et al. (2023) presents empirical evidence of the existence of lower bound under NIRP. Ueno (2017) analyzes Japanese NIRP using a term structure model.

Figure 4: Shadow Rates



A. The subsample analysis: 1990 and 2015



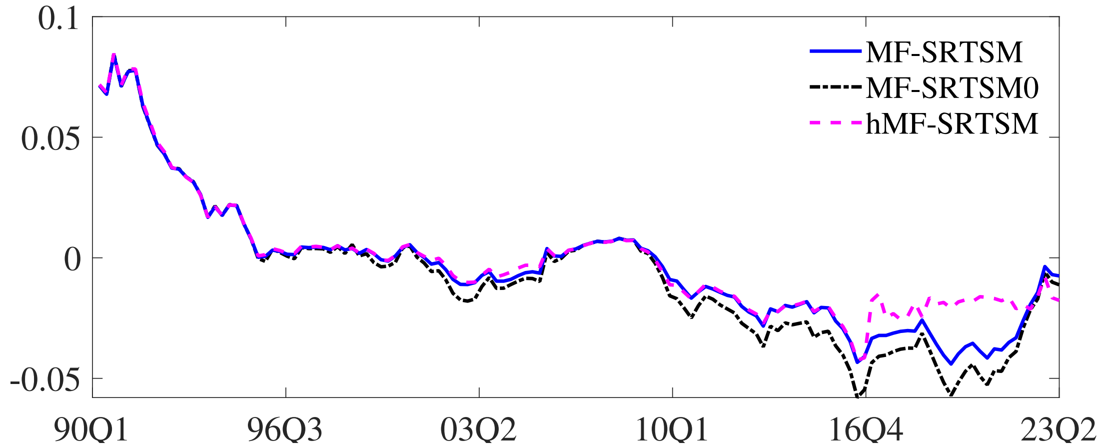
B. The whole sample period analysis: 1990 and 2023Q2

Note: The solid blue line shows the MF-SRTSM shadow rate, the dashed red line shows the SRTSM shadow rate, the black dash-dotted line shows the MF-SRTSM0 shadow rate, and the green dotted line shows the MF-GTSM shadow rate. Whole sample (1990Q1-2023Q2), subsample (1990Q1-2015Q4. Forward rates in 1, 2, 4, 8, 20, 28, and 40 quarters are used in estimation as in Wu and Xia (2016).

the positive omitted variable biases in estimating the persistence parameters in the SRTSM, thereby generating a slightly higher shadow rate. In other words, the MF-SRTSM0 shadow rate (black dash-dotted line) lies above the SRTSM shadow rate (red dashed line).

Incorporating outcome-based forward guidance further accounts for the impact of the macro factors on forward rates through the liftoff condition, thereby generating a shallower shadow rate. On average, the MF-SRTSM shadow rate (blue solid line) lies above the MF-

Figure 5: Shadow rates: forward guidance and YCC effects



Note: The pink dashed line shows the hMF-SRTSM shadow rate, and the black dash-dotted line shows the MF-SRTSM0 shadow rate. The sample period is 1990Q1 through 2023Q2. Forward rates in 1, 2, 4, 8, 20, 28, and 40 quarters are used in estimation as in Wu and Xia (2016).

SRTSM0 shadow rate (black dash dotted line) for 69%, 36%, and 23% of the latter rate during the BOJ's zero-interest rate policy period (1999Q1-2000Q2), the first quantitative easing period (2001Q1-2006Q1), and BOJ's QQE period (2013Q1-), respectively.[9] This implies that forward guidance played a more significant role during the initial phase of unconventional monetary policies. The scale of each policy type can be understood as the proportion of its associated shadow rate in comparison to the SRTSM shadow rate. These shadow rates are used in the next section to assess the macroeconomic effect of outcome-based forward guidance.

Figure 5 depicts the shadow rates using the hypothetical forward rate (pink dashed line, hMF-SRTSM) together with the MF-SRTSM and MF-SRTSM0 shadow rates. Examining the gap between the pick-dashed and blue-solid lines, the figure indicates that the YCC had lowered the shadow rate by 161 basis points on average during 2016Q4 and 2022Q1, which accounted for over a third of the overall policy impact during this period. This effect, however, has diminished since March 2022.

5 Macroeconomic effects

We use the factor augmented vector autoregression (FAVAR) model in Bernanke et al. (2005) to assess the macroeconomic effect of unconventional monetary policies following Wu and Xia

[9] In calculating the average, we exclude periods when either the MF-SRTSM or MF-SRTSM0 shadow rate is positive.

(2016) and Koeda and Wei (2023). For additional macroeconomic variables in FAVAR estimation, we refer to a database constructed by Koeda et al. (2023) for a large set of observed macroeconomic variables. Appendix Table D-1 offers further details on the macroeconomic variables sourced from the database.[10]

We explore counterfactual scenarios by analyzing two distinct periods: one includes the implementation of QQE from the first quarter of 2013 to the first quarter of 2018, and another subsequent to the introduction of YCC from the fourth quarter of 2016 to the fourth quarter of 2020. The baseline scenario is based on responses from the FVAR estimation, utilizing the SRTSM shadow rate as the policy rate.

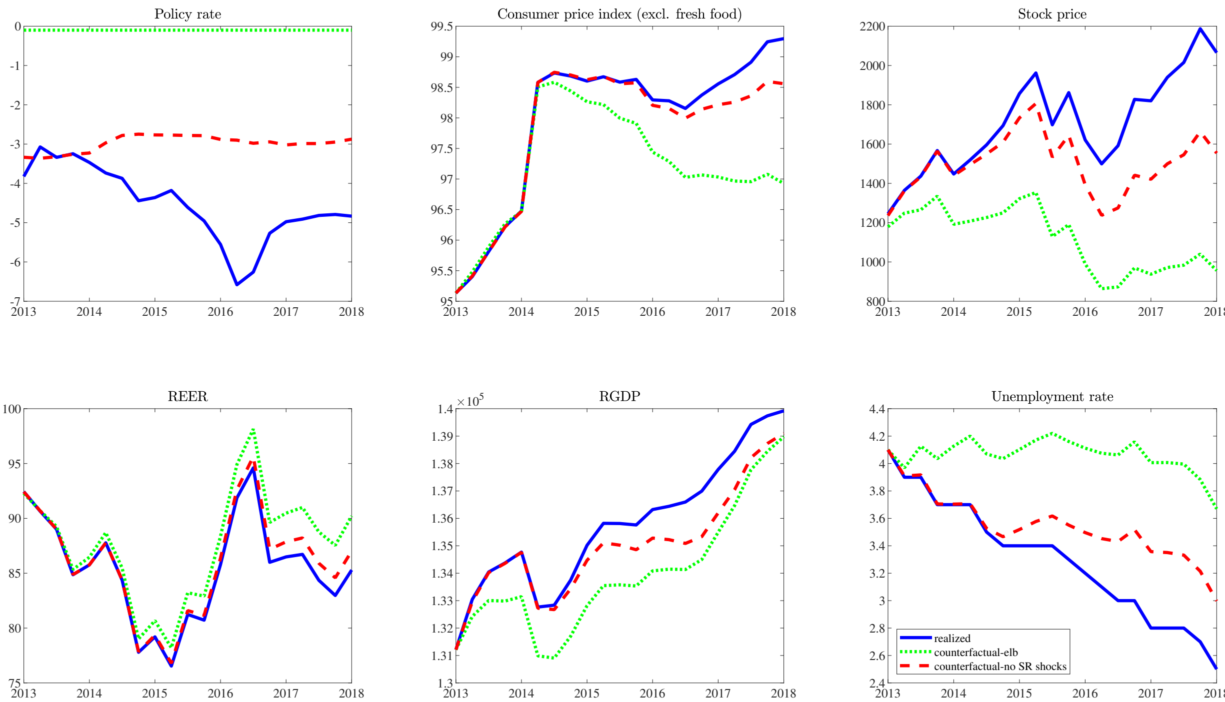
Figure 6 presents historical decomposition following Wu and Xia (2016). We plot the observed time series for the six variables in blue: the policy rate, CPI excluding fresh food (known as "core" CPI in Japan), stock price (Tokyo Stock Price Index), real effective exchange rate (REER), real GDP, and unemployment. We plot counterfactual paths shutting down monetary policy shocks (black dashed lines) and when the shadow rate is kept at the ELB (green dotted lines). On average, the shadow rate would have been 154 basis points higher between 2013Q1-2018Q1, and QQE has actively lowered the shadow rate. In contract, Figure 7 indicates that during the first few years of YCC, the shadow rate would have been 99 basis points lower between 2016Q4-2018Q4, and YCC was not an expansionary policy initially.

We determine the responses of different economic variables when monetary policy shocks are aligned to reproduce the MF-SRTSM0 shadow rate (Counterfactual I), MF-SRTSM shadow rate (Counterfactual II), the ELB (Counterfactual-elb), or hMF-SRTSM shadow rate (Counterfactual-h). Given the challenge of completely isolating shocks other than monetary policy that influence ϵ_t^{MP}, we focus on the difference in the responses rather than the levels of responses.

Overall, the magnitude of additional unconventional monetary policies at the ELB is captured by the differences in responses under Counterfactual-elb and actual responses (green dotted and blue solid lines) in Figures 8 and 9. The CPI excluding fresh food would have declined in response to falling energy prices in 2015 (top middle, Figure 8). The estimated effect on prices is broadly in line with BOJ (2021). The stock price would have been 48% lower (top right, Figure 8), the real effective exchange rate would have appreciated by 6% (bottom left, Figure 8), and the unemployment rate would have been about 1.2 percentage points higher (bottom right, Figure 8) than the realized values in 2018Q1.

[10] Extending Shintani (2005), Maehashi and Shintani (2020) construct a monthly macroeconomic database for Japan that extends until 2022. Our database is quarterly and includes the National Income Accounting data.

FIGURE 6: QQE: Macroeconomic effects



NOTE: The solid blue lines show the SRTSM shadow rate (top left) and the observed economic variables between 2013Q1 and 2018Q1. The red dashed line shows what would occur to these variables, if all the monetary policy shocks were shut down. The green dotted lines show what would have happened if the shadow rate were kept at the lower bound.
SOURCE: Authors' calculations.

The magnitude of outcome-based forward guidance is estimated to exceed 90 basis points, on average, between 2013Q1-2018Q1 and between 2016Q3 and 2021Q4, captured by the difference between the shadow rates under the scenarios in Counterfactual I and II (black dashed and red dot-dashed lines). The magnitude of YCC is estimated to be about 90 basis points on average between 2016Q3 and 2021Q4, captured by the differences between the shadow rates under the Counterfactual-h and II scenarios (the pink dotted and red dash-dotted lines) in Figure 9. In the absence of YCC, the shadow rate would have been 1.6% shallower (top left, Figure 9), the stock price would have been 21% lower (top right, Figure 9), and the unemployment rate would have been 0.4% percentage points higher (bottom right, Figure 9) in 2020Q4. The magnitude of other policy effects, particularly with respect to asset purchases, is captured by the remaining part of the shadow rate. This is reflected in the differences between the shadow rates under the Counterfactual II and III scenarios in Figure 8, and those between Counterfactuals III and IV, as illustrated by the pink solid and green dotted lines in Figure 9. Despite the challenges associated with reversing the asset

FIGURE 7: YCC: Macroeconomic effects

NOTE: Solid blue lines show the SRTSM shadow rate (top left) and the observed economic variables between 2016Q4 and 2020Q4. The red dashed line shows what would occur to these variables, if all the monetary policy shocks were shut down. The green dotted lines show what would have happened if the shadow rate were kept at the lower bound.
SOURCE: Authors' calculations.

purchases, these actions contributed to stimulating the economy.

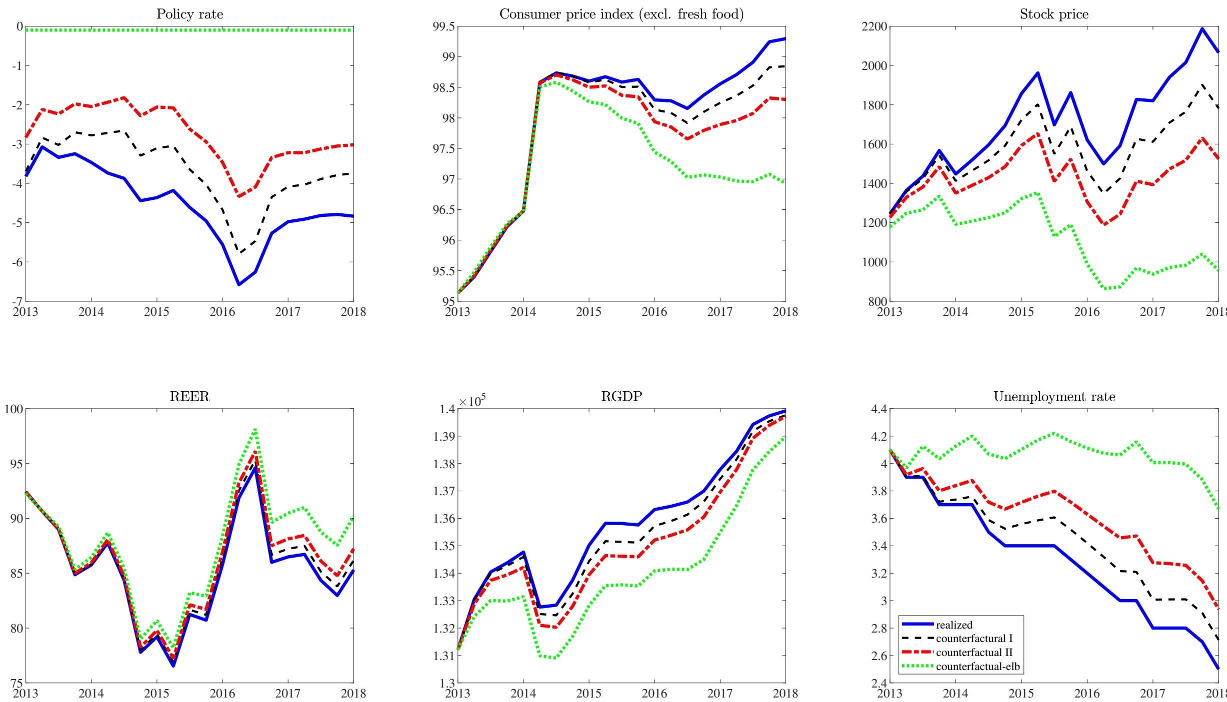
6 Conclusion

This article has comprehensively assessed the effectiveness of Japan's unconventional monetary policies over the past quarter-century, emphasizing the impact of the BOJ's outcome-based forward guidance and YCC. Our analysis indicates that these policies have been instrumental in Japan's economic management during a prolonged low-interest-rate period.

The study shows that outcome-based forward guidance has been a consistent and effective tool at the ELB, particularly crucial in the early stages of the extended ELB environment. The adoption of YCC in 2016 represented a significant shift in the BOJ's approach, accounting for over a third of the policy impact up to March 2022, though its effect has waned since then with more positive inflation.

Future research avenues remain open. One area of interest involves exploring variations in

FIGURE 8: QQE: Observed and Counterfactual Macroeconomic Variables



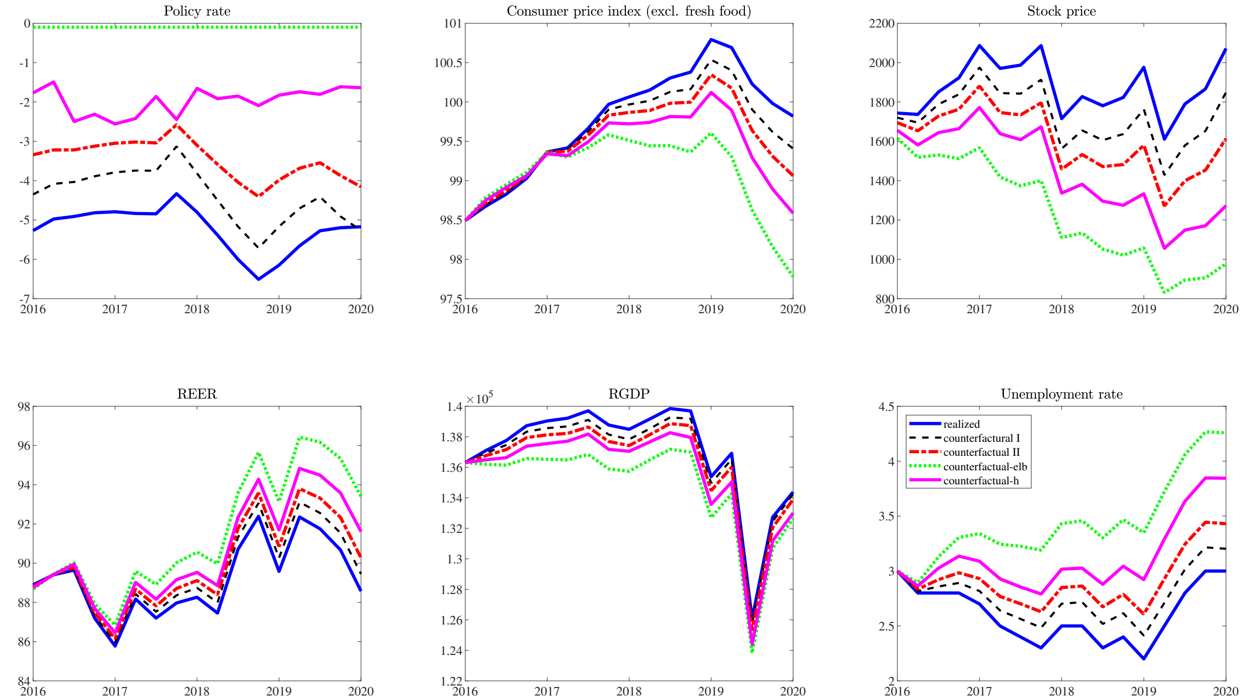
NOTE: The solid blue lines show the SRTSM shadow rate (top left) and the observed economic variables between 2013Q1 and 2018Q1. The black dashed (red dot-dashed) lines show what would occur to these variables, if the monetary policy shocks were set to generate the MF-SRTSM0 (MF-SRTSM) shadow rate. The green dotted lines show what would have happened if the shadow rate were kept at the lower bound.
SOURCE: Authors' calculations.

how forward guidance is represented in a term structure model. Orphanides (2023) examines the advantages of forecast-based forward guidance over outcome-based guidance. Our findings suggest that an outcome-based framework could align with forecast-based guidance if inflation expectations are adaptive or if the inflation liftoff condition shifts to a model-based inflation forecast.

A critical point of consideration is the highly negative shadow rates achieved during QQE, facilitated by substantial unconventional asset purchases. As highlighted in the BOJ's first "Review of Monetary Policy from a Broad Perspective" meeting on December 4, 2023, these purchases may have unintended repercussions, such as impairing market functionality and banking sector profitability. Therefore, it is essential to weigh the immediate benefits of these monetary policies against their potential long-term costs, especially considering future generations.

In summary, this article contributes to our understanding of the role and impact of unconventional monetary policies in Japan, providing insights into their application and

Figure 9: YCC: Observed and Counterfactual Macroeconomic Variables



Note: Solid blue lines show the SRTSM shadow rate (top left) and the observed economic variables between 2016Q4 and 2020Q4. The pink solid lines show what would have happened if the monetary policy shocks were set to generate the hMF-SRTSM shadow rate (Counterfactual-h). The black dashed (red dot-dashed/green dotted) lines show what would occur to these variables, if the monetary policy shocks were set to generate the MF-SRTSM0 (MF-SRTSM/MF-GTSM) shadow rate.
Source: Authors' calculations.

effects in a sustained low-interest-rate context.

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Table 1: Statements Related to Outcome-based Forward Guidance by the Bank of Japan, 1999-2023Q2

Date	Statement
1999.4.13	"(The BOJ will) continue to supply ample funds until the deflationary concern is dispelled." (Remark by Governor Hayami in a Q& A session with the press. Translation by authors.)
1999.9.21	"The Bank of Japan has been pursuing an unprecedented accommodative monetary policy and is explicitly committed to continue this policy until deflationary concerns subside."
2000.8.11	"... the downward pressure on prices ... has markedly receded...deflationary concern has been dispelled, the condition for lifting the zero interest rate policy."
2001.3.19	"The main operating target for money market operations be changed from the current uncollateralized overnight call rate to the outstanding balance of the current accounts at the BOJ. Under the new procedures, the Bank provides ample liquidity, and the uncollateralized overnight call rate will be determined in the market The new procedures for money market operations continue to be in place until the consumer price index (excluding perishables, on a nationwide statistics) registers stably a 0% or an increase year on year."
2003.10.10	"The BOJ is currently committed to maintaining the quantitative easing policy until the consumer price index (excluding fresh food, on a nationwide basis) registers stably a zero percent or an cincrease year on year."
2006.3.9	"Concerning prices, year-on-year changes in the consumer price index turned positive. Meanwhile, the output gap is gradually narrowing. In this environment, year-on-year changes are expected to remain positive. The Bank, therefore, judged that the conditions laid out in the commitment are fulfilled."
2009.12.18	"The Policy Board does not tolerate a year-on-year rate of change in the CPI equal to or below 0 percent."
2010.10.5	"The Bank will maintain the virtually zero interest rate policy until it judges, on the basis of the 'understanding of medium- to long-term price stability' that price stability is in sight."
2012.2.14	"The Bank will continue pursuing the powerful easing until it judges that the 1% goal is in sight."
2013.1.22	"The Bank sets the "price stability target" at 2% in terms of the year-on-year rate of change in the consumer price index (CPI)"
2013.4.4	"The Bank will continue with the quantitative and qualitative monetary easing, aiming to achieve the price stability target of 2%, as long as it is necessary for maintaining that target in a stable manner."
2016.1.29	"The Bank will continue with "QQE with a Negative Interest Rate," aiming to achieve the price stability target of 2%, as long as it is necessary for maintaining that target in a stable manner."
2016.9.21	"The Bank will continue with "QQE with Yield Curve Control," aiming to achieve the price stability target of 2%, as long as it is necessary for maintaining that target in a stable manner."

Note: Excerpts from policy statements by the Bank of Japan, including phrases frequently mentioned in subsequent releases.

Table 2: Statements Related to the ELB by the Bank of Japan, 1999-2023Q2

Date	Statements
1999.2.12	"The Bank of Japan will provide more ample funds and encourage the the uncollateralized overnight call rate to move as low as possible."
2001.3.19	"...it is anticipated that the uncollateralized overnight call rate will significantly decline from the current target level of 0.15 percent and stay close to zero percent under normal circumstances."
2008.10.31	"To ensure stability in money markets, a temporary measure will be introduced to pay interest on excess reserve balances... the interest rate applied will be 0.1 percent"
2008.12.19	"Interest rate applied to the complementary deposit facility (author note: which is IOER) will be 0.1 percent."
2016.1.29	"The Bank will apply a negative interest rate of minus 0.1 percent to current accounts that financial institutions hold at the Bank."

Note: Excerpts from policy statements by the Bank of Japan, including phrases frequently mentioned in subsequent releases.

Table 3: Statements Related to YCC by the Bank of Japan, 1999-2023Q2

Date	Statements
2016.9.21	"The guideline for market operations specifies a short-term policy interest rate and a target level of a long-term interest rate...The Bank will purchase Japanese government bonds (JGBs) so that 10-year JGB yields will remain more or less at the current level (around zero percent).
2021.3.19	"the Bank will make clear that the range of 10-year Japanese government bond (JGB) yield fluctuations would be between around plus and minus 0.25 percent from the target level. At the same time, it will introduce "fixed-rate purchase operations for consecutive days" as a powerful tool to set an upper limit on interest rates when necessary."
2022.12.20	"the Bank will expand the range of 10-year JGB yield fluctuations from the target level: from between around plus and minus 0.25 percentage points to between around plus and minus 0.5 percentage points."

Note: Excerpts from policy statements by the Bank of Japan, including phrases frequently mentioned in subsequent releases.

Table 4: MF-SRTSM0 Estimated Parameters: 1990Q1-2015Q4

$400\mu_Z$	1.63	−2.29	−0.11	1.26	0.17
	(2.52)	(3.79)	(0.36)	(4.83)	(1.08)
ρ_Z	0.99	0.16	0.67	0.01	−0.10
	(0.08)	(0.10)	(0.76)	(0.06)	(0.07)
	−0.02	0.76	0.10	0.03	0.08
	(0.12)	(0.10)	(1.37)	(0.05)	(0.14)
	0.01	0.02	0.71	0.01	−0.01
	(0.02)	(0.02)	(0.09)	(0.00)	(0.02)
	0.05	−0.22	0.39	0.74	−0.17
	(0.10)	(0.29)	(3.57)	(0.09)	(0.21)
	0.02	0.06	−0.35	0.10	0.79
	(0.04)	(0.09)	(0.55)	(0.03)	(0.07)
$\rho^{\mathbb{Q}}_{XX}$	0.99				
	(0.00)				
		0.88	1.00		
		(0.01)			
			0.88		
			(0.01)		
$400r^{\mathbb{Q}}_{\infty}$	6.91				
	(0.57)				
$\sqrt{400}\Sigma_Z$	0.13				
	(0.01)				
	−0.09	0.09			
	(0.01)	(0.02)			
	−0.01	0.00	0.02		
	(0.00)	(0.00)	(0.01)		
	0.01	0.04	−0.28	−0.06	
	(0.07)	(0.12)	(0.04)	(0.23)	
	−0.10	−0.03	−0.01	0.00	−0.04
	(0.01)	(0.04)	(0.04)	(0.07)	(0.01)
$\sigma_e \cdot 10^4$	7.04				
	(0.43)				
LLV	4489.3				

Note: Parameter estimates for MF-SRTSM0. Standard errors are reported in parentheses.

Table 5: MF-SRTSM Estimated Parameters: 1990Q1-2015Q4

$400\mu_Z$	3.12	−4.47	−0.49	4.57	1.83
	(0.00)	(0.00)	(0.00)	(4.33)	(0.99)
ρ_Z	1.04	0.29	0.57	0.03	−0.16
	(0.01)	(0.00)	(0.45)	(0.04)	(0.15)
	−0.09	0.68	−0.13	0.03	0.20
	(0.03)	(0.00)	(0.61)	(0.05)	(0.09)
	0.00	0.01	0.71	0.01	0.01
	(0.00)	(0.02)	(0.00)	(0.01)	(0.03)
	0.12	0.00	0.56	0.80	−0.03
	(0.06)	(0.14)	(4.65)	(0.08)	(0.19)
	0.04	0.14	−0.17	0.10	0.79
	(0.04)	(0.16)	(1.01)	(0.03)	(0.04)
$\rho^{\mathbb{Q}}_{XX}$	0.99				
	(0.00)				
		0.88	1.00		
		(0.01)			
			0.88		
			(0.01)		
$400r^{\mathbb{Q}}_{\infty}$	6.80				
	(0.00)				
$\sqrt{400}\Sigma_Z$	0.13				
	(0.01)				
	−0.10	0.07			
	(0.01)	(0.00)			
	−0.01	0.00	0.02		
	(0.00)	(0.00)	(0.00)		
	−0.05	0.13	−0.19	0.20	
	(0.00)	(0.03)	(0.06)	(0.02)	
	−0.02	0.12	0.07	0.00	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)
$\sigma_e \cdot 10^4$	7.31				
	(0.00)				
LLV	4452.0				

Note: Parameter estimates for MF-SRTSM. Standard errors are reported in parentheses.

Table 6: SRTSM Estimated Parameters:
1990Q1-2015Q4

$400\mu_X$	-0.02	-1.41	-0.25
	(1.13)	(0.81)	(0.23)
ρ_{XX}	0.95	0.12	0.47
	(0.34)	(0.28)	(7.70)
	0.00	0.75	0.36
	(0.36)	(0.41)	(5.30)
	0.00	0.01	0.74
	(0.03)	(0.16)	(1.24)
$\rho^{\mathbb{Q}}_{XX}$	0.99		
	(0.00)		
		0.88	1.00
		(0.03)	
			0.88
			(0.03)
$400r^{\mathbb{Q}}_{\infty}$	7.14		
	(1.25)		
$\sqrt{400}\Sigma_{XX}$	0.13		
	(0.11)		
	-0.09	0.09	
	(0.05)	(0.03)	
	-0.01	0.00	0.02
	(0.02)	(0.01)	(0.00)
$\sigma_e \cdot 10^4$	7.08		
	(2.40)		
LLV	3804.3		

Note: Parameter estimates for SRTSM. Standard errors are reported in parentheses.

Table 7: MF-GTSM Estimated Parameters: 1990Q1-2015Q4

$400\mu_Z$	2.80	−2.61	−0.49	7.71	1.57
	(0.71)	(0.99)	(0.33)	(3.16)	(1.08)
ρ_Z	1.09	0.12	0.70	−0.01	−0.11
	(0.00)	(0.10)	(1.04)	(0.08)	(0.09)
	−0.10	0.82	0.25	0.02	0.08
	(0.04)	(0.10)	(0.76)	(0.04)	(0.05)
	−0.01	−0.01	0.77	0.01	0.01
	(0.01)	(0.01)	(0.14)	(0.00)	(0.01)
	0.26	0.14	0.53	0.75	−0.60
	(0.13)	(0.28)	(1.68)	(0.09)	(0.22)
	0.07	0.09	−0.07	0.08	0.73
	(0.05)	(0.07)	(0.43)	(0.03)	(0.08)
$\rho^{\mathbb{Q}}_{XX}$	0.99				
	(0.00)				
		0.89	1.00		
		(0.01)			
			0.89		
			(0.01)		
$400r^{\mathbb{Q}}_{\infty}$	6.54				
	(0.52)				
$\sqrt{400}\Sigma_Z$	0.14				
	(0.02)				
	−0.10	0.05			
	(0.02)	(0.01)			
	0.00	0.00	0.01		
	(0.00)	(0.00)	(0.00)		
	−0.01	0.22	−0.02	0.18	
	(0.04)	(0.03)	(0.02)	(0.02)	
	−0.11	−0.01	0.00	0.00	0.05
	(0.03)	(0.01)	(0.02)	(0.02)	(0.08)
$\sigma_e \cdot 10^4$	7.33				
	(0.57)				
LLV	4476.1				

Note: Parameter estimates for MF-GTSM. Standard errors are reported in parentheses.

Table 8: Estimated Parameters of MF-SRTSM0: 1990Q1-2023Q2

$400\mu_Z$	1.51	−2.93	−0.15	4.85	0.37
	(1.60)	(1.80)	(0.31)	(3.05)	(1.05)
ρ_Z	1.01	0.18	0.37	0.01	−0.10
	(0.03)	(0.12)	(1.04)	(0.03)	(0.06)
	−0.07	0.74	0.34	0.05	0.15
	(0.04)	(0.13)	(1.50)	(0.03)	(0.07)
	0.00	0.02	0.73	0.01	0.00
	(0.02)	(0.04)	(0.15)	(0.01)	(0.02)
	0.09	−0.22	1.99	0.70	−0.02
	(0.09)	(0.52)	(3.00)	(0.09)	(0.06)
	0.00	0.07	0.00	0.10	0.84
	(0.03)	(0.07)	(0.04)	(0.02)	(0.05)
$\rho^{\mathbb{Q}}_{XX}$	0.99				
	(0.00)				
		0.88	1		
		(0.01)			
			0.88		
			(0.01)		
$400r^{\mathbb{Q}}_{\infty}$	6.90				
	(0.46)				
$\sqrt{400}\Sigma_Z$	0.13				
	(0.01)				
	−0.09	0.08			
	(0.01)	(0.01)			
	−0.01	0.00	0.02		
	(0.00)	(0.00)	(0.01)		
	−0.06	0.30	0.03	0.18	
	(0.03)	(0.05)	(0.10)	(0.06)	
	−0.10	−0.01	−0.01	0.00	0.05
	(0.01)	(0.01)	(0.03)	(0.02)	(0.01)
$\sigma_e \cdot 10^4$	7.74				
	(0.55)				
LLV	5785.5				

Note: Parameter estimates for MF-SRTSM0. Standard errors are reported in parentheses.

TABLE 9: Estimated Parameters of MF-SRTSM: 1990Q1-2023Q2

$400\mu_Z$	3.21	−4.57	−0.46	4.98	1.94
	(1.02)	(1.17)	(0.00)	(0.98)	(0.57)
ρ_Z	1.05	0.28	0.56	0.01	−0.17
	(0.01)	(0.00)	(0.64)	(0.02)	(0.05)
	−0.10	0.68	−0.17	0.03	0.19
	(0.02)	(0.00)	(0.66)	(0.03)	(0.06)
	0.00	0.01	0.71	0.01	0.00
	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)
	0.10	0.01	0.48	0.76	−0.01
	(0.03)	(0.06)	(0.61)	(0.05)	(0.10)
	0.03	0.15	−0.14	0.11	0.79
	(0.01)	(0.09)	(0.65)	(0.02)	(0.04)
$\rho^{\mathbb{Q}}_{XX}$	0.99				
	(0.00)				
		0.88	1		
		(0.01)			
			0.88		
			(0.01)		
$400r^{\mathbb{Q}}_{\infty}$	7.06				
	(0.34)				
$\sqrt{400}\Sigma_Z$	0.14				
	(0.01)				
	−0.11	0.07			
	(0.01)	(0.00)			
	0.00	0.00	0.02		
	(0.00)	(0.00)	(0.00)		
	−0.09	0.19	−0.12	0.27	
	(0.01)	(0.01)	(0.01)	(0.01)	
	0.00	0.09	0.09	0.00	0.00
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
$\sigma_e \cdot 10^4$	7.84				
	(0.00)				
LLV	5755.0				

NOTE: Parameter estimates for MF-SRTSM. Standard errors are reported in parentheses.

Table 10: Estimated Parameters of SRTSM: 1990Q1-2023Q2

$400\mu_X$	0.59	-1.59	-0.38
	(5.99)	(0.88)	(1.31)
ρ_{XX}	0.98	0.16	0.33
	(0.29)	(1.43)	(10.13)
	-0.02	0.72	0.64
	(0.11)	(0.47)	(5.96)
	-0.01	0.00	0.78
	(0.05)	(0.24)	(1.31)
$\rho^{\mathbb{Q}}_{XX}$	0.99		
	(0.01)		
		0.88	1
		(0.07)	
			0.88
			(0.07)
$400r^{\mathbb{Q}}_{\infty}$	7.10		
	(2.19)		
$\sqrt{400}\Sigma_{XX}$	0.14		
	(0.29)		
	-0.09	0.09	
	(0.17)	(0.10)	
	-0.01	0.00	0.02
	(0.06)	(0.01)	(0.00)
$\sigma_e \cdot 10^4$	7.78		
	(2.73)		
LLV	4928.3		

Note: Parameter estimates for SRTSM. Standard errors are reported in parentheses.

Table 11: Estimated Parameters of MF-GTSM: 1990Q1-2023Q2

$400\mu_Z$	2.24	−2.48	−0.44	8.79	0.39
	(1.05)	(0.97)	(0.31)	(6.68)	(9.43)
ρ_Z	1.09	0.08	0.76	−0.01	−0.08
	(0.01)	(0.04)	(3.03)	(0.19)	(0.07)
	−0.10	0.85	0.03	0.02	0.06
	(0.04)	(0.06)	(2.09)	(0.11)	(0.03)
	−0.02	−0.01	0.77	0.00	0.01
	(0.01)	(0.02)	(0.14)	(0.00)	(0.01)
	0.32	0.29	1.09	0.64	−0.36
	(0.27)	(0.82)	(9.17)	(0.13)	(0.19)
	0.01	0.02	0.08	0.09	0.84
	(0.20)	(0.34)	(13.76)	(0.05)	(0.22)
$\rho^{\mathbb{Q}}_{XX}$	0.99				
	(0.00)				
		0.91	1		
		(0.01)			
			0.91		
			(0.01)		
$400r^{\mathbb{Q}}_{\infty}$	5.92				
	(1.10)				
$\sqrt{400}\Sigma_Z$	0.15				
	(0.02)				
	−0.10	0.05			
	(0.02)	(0.01)			
	0.00	0.00	0.01		
	(0.00)	(0.00)	(0.00)		
	0.00	0.33	−0.13	−0.05	
	(0.51)	(0.06)	(0.22)	(0.34)	
	−0.01	0.00	0.00	−0.01	0.11
	(0.26)	(0.08)	(0.16)	(0.04)	(0.01)
$\sigma_e \cdot 10^4$	6.65				
	(0.53)				
LLV	5818.9				

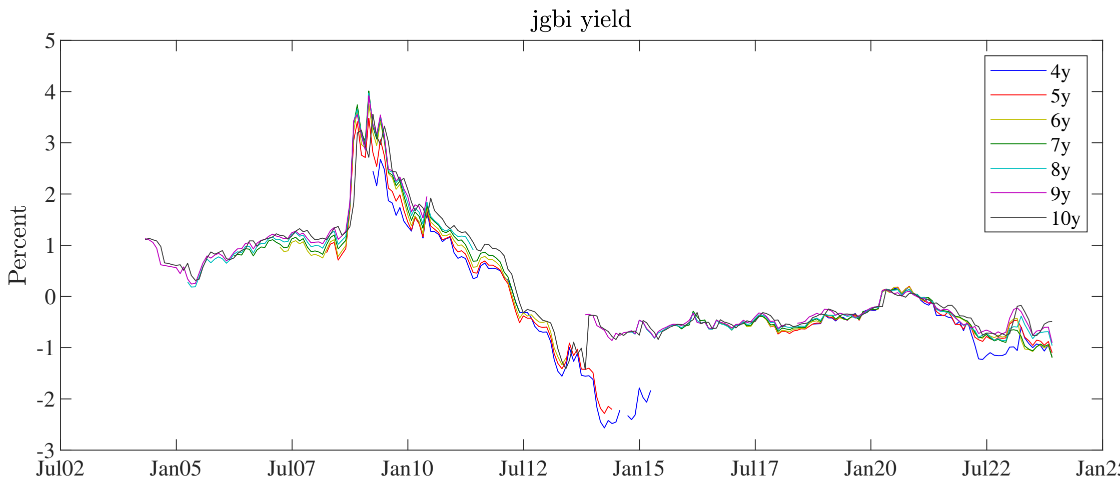
Note: Parameter estimates for MF-GTSM. Standard errors are reported in parentheses.

A The construction of hypothetical nominal yields

This section documents the construction of the yield for hypothetical inflation-indexed Japanese governement bond (JGBi). The Japanese government has issued 10-year JGBi since 2004. There have been fewer than 30 issues to date, and in addition, after September 2008, the Japanese government did not issue JGBi for several years. To construct JGBi yields by remaining maturity with such limited data, the following steps were taken.

First, we obtain bond yield data for each JGBi from Bloomberg. Second, we convert them from a daily to a monthly frequency. Given the end of month values are often missing, we use the value closest to the end of each month. Third, we compute the remaining years to maturity for each issue each month.[11] After these steps of data conversion, there are still missing values. The converted JGBi yields are presented in Figure A-1

FIGURE A-1: JGBi yields by remaining years of maturity



Second, we fit two-factor Nelson-Siegel curves on the converted JGBi yields (setting the decay factor equals to 0.03) for periods where at least four observed yields of different maturities are available. Some periods do not have values as data are too limited to fit an NS curve. Figure A-2

Third, we regress the n-year JGB yield on a constant, n-year JGBi yield, and ESP inflation forecast measure using the subsample period of April 2004 to December 2015.[12] We then compute the fitted values to construct a hypothetical nominal yield for the remaining years to maturity. We construct hypothetical yields from December 2016 excluding the quarter that YCC was introduced, thereby allowing the markets time to incorporate the YCC. The fitted yields are presented in Figures A-6- A-8. We replace the observed 5-10 year bond yields with the fitted yields to construct the hypothetical yields.

[11]There are several small steps to construct the remaining years to maturity. First, JGBi yield data with a short remaining years to maturity often swing. Therefore, we only use JGBi yield data with 4-10 years remaining maturity. Second, we take the average yields for each issue that falls into a specific maturity range (e.g., if the remaining maturity is less than or equal to n years but greater than n-1 year this maturity falls into the n years remaining group).

[12]For the ESP measure, we use a 1-year ahead inflation forecast.

Figure A-2: Fitted curves on JGBi yields

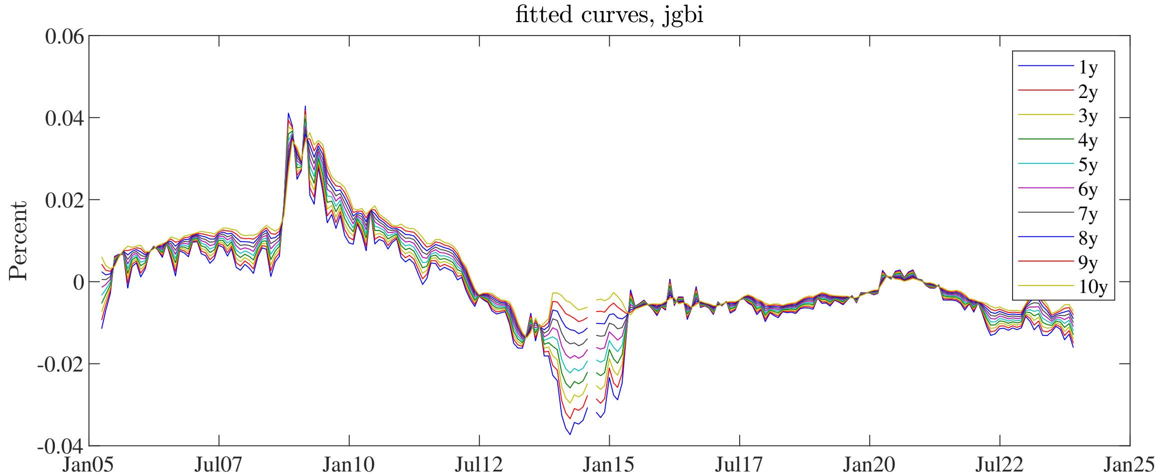
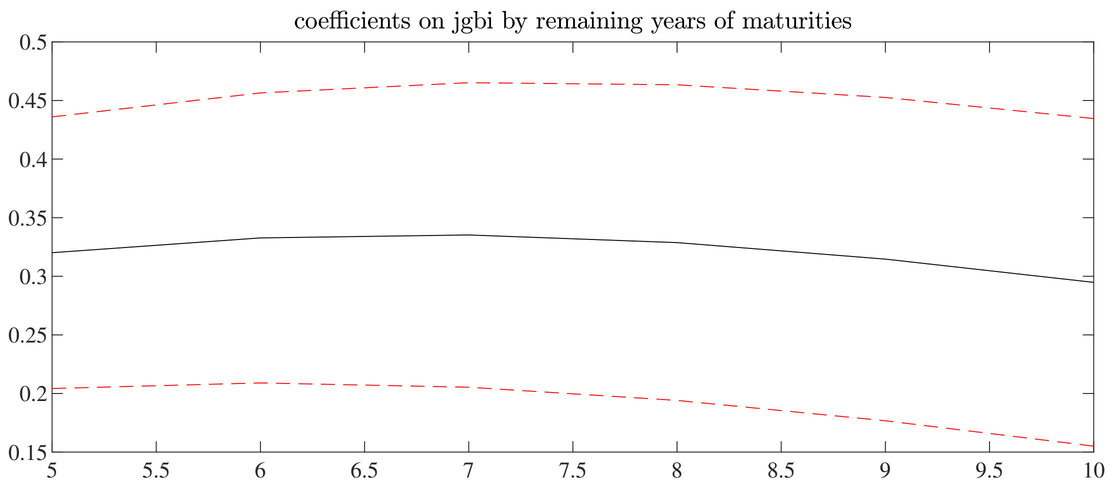


Figure A-3: JGBI coefficients



Lastly, we fit three-factor Nelson-Siegel curves to the hypothetical yields to compute bond yields for all maturities, and re-calculate the hypothetical forward rate. Figure A-9 presents the hypothetical nominal yields.

Figure A-4: Coefficients on expected inflation

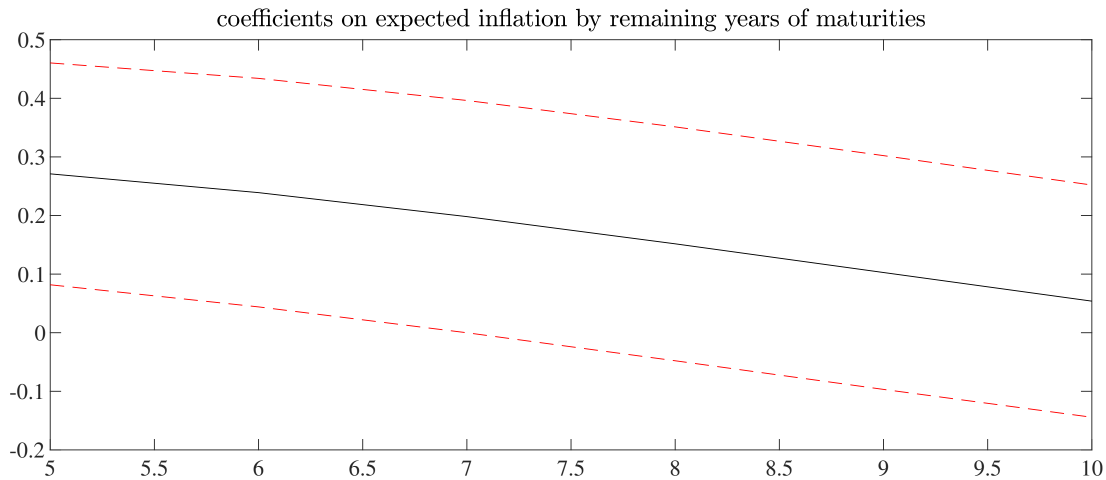


Figure A-5: Coefficients on constant

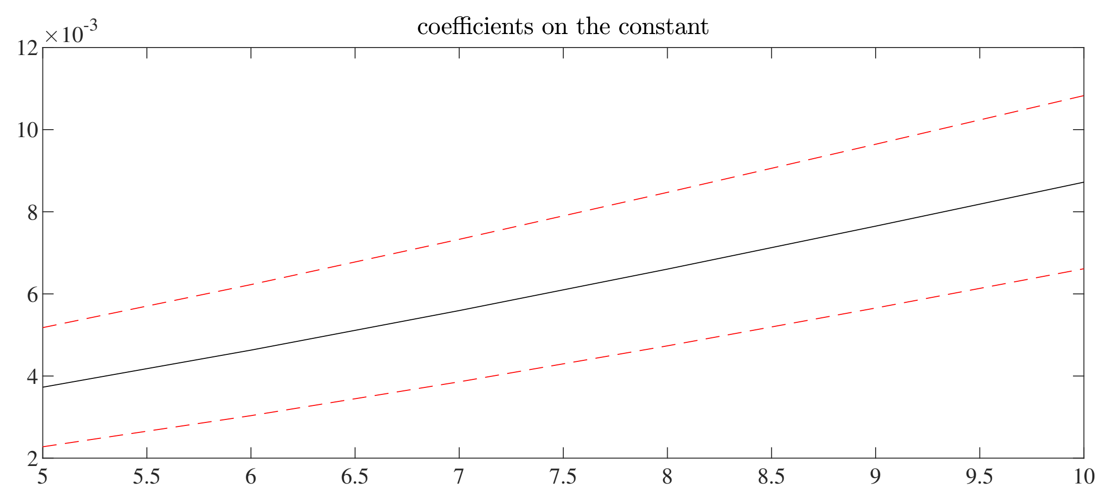


Figure A-6: Nominal 10-year yield and fitted values

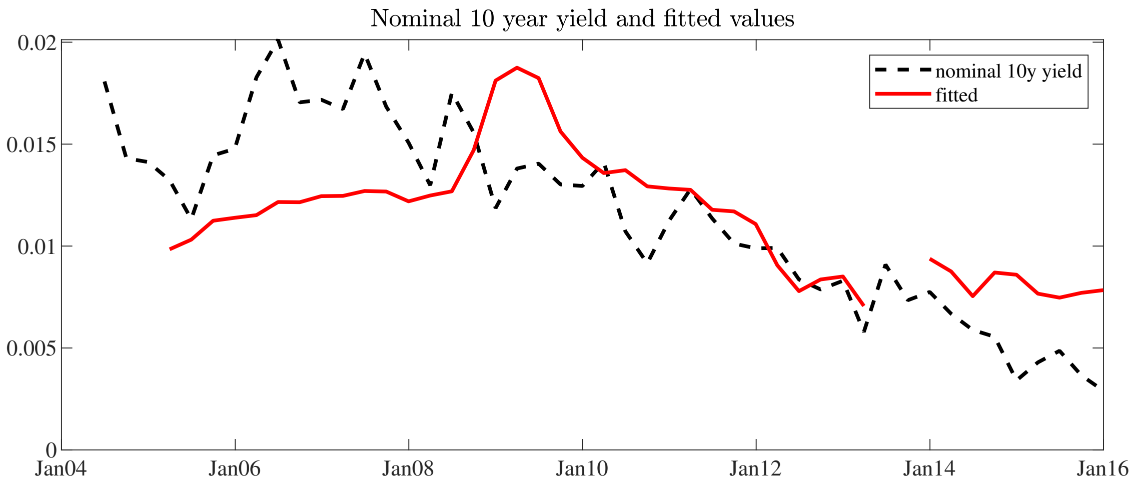


Figure A-7: Nominal 7-year yield and fitted values

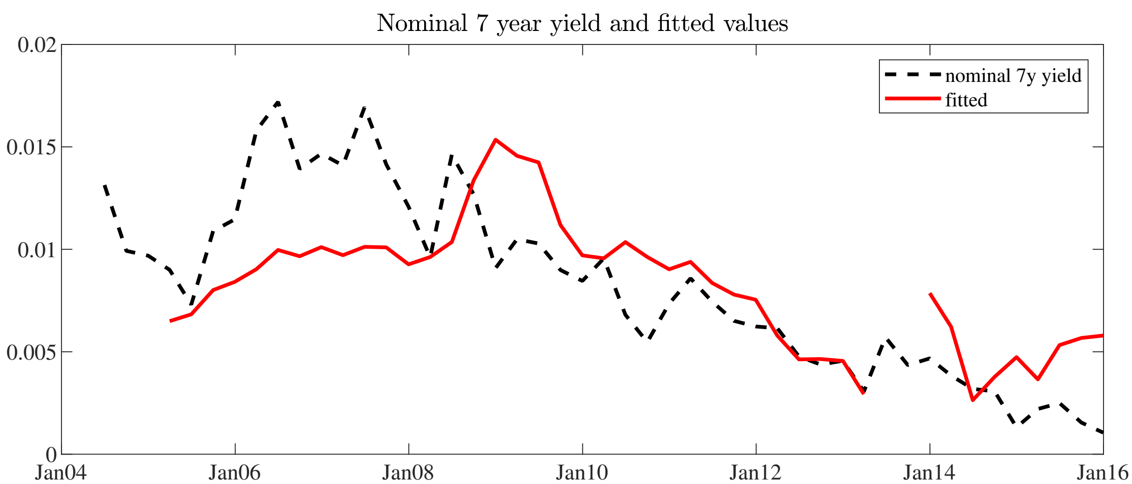


Figure A-8: Nominal 5-year yield and fitted values

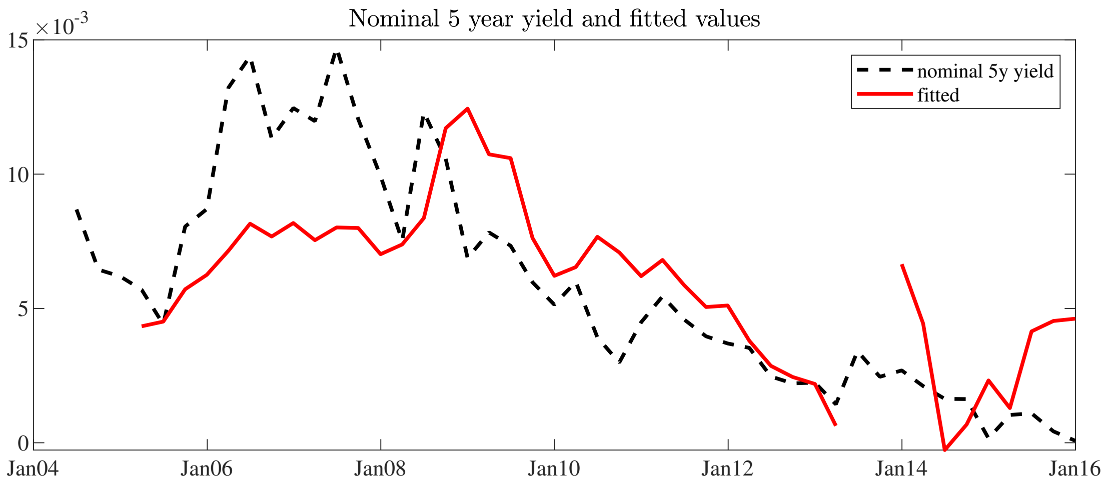
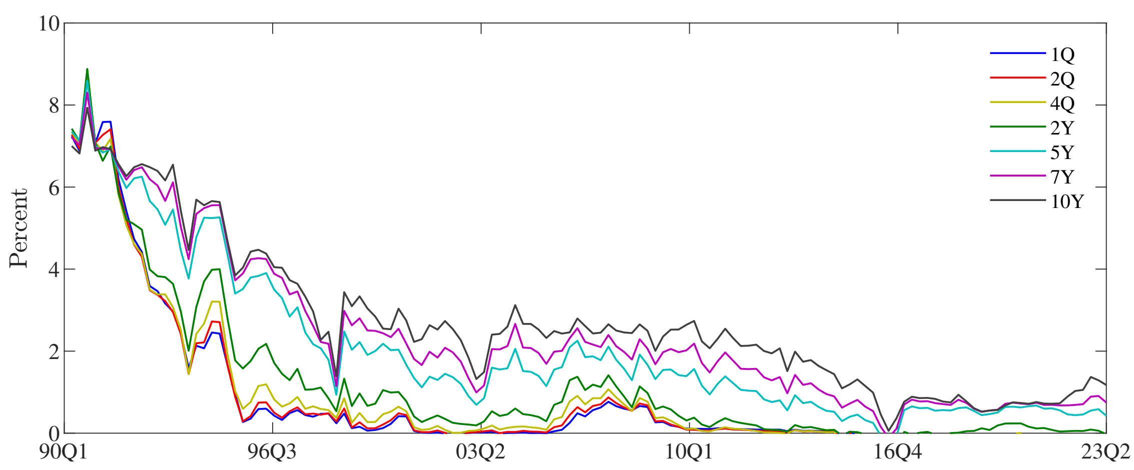


Figure A-9: Hypothetical forward rates for Japan (1990Q1 to 2023Q2)



B The Model

Let $\widehat{M}_t = M_t - \chi X_t$ and choose the constant χ to be the solution to

$$\chi \kappa_{11}^{*} - \kappa_{22}^{*} \chi = \kappa_{21}^{*}. \tag{B-1}$$

Denote

$$\sigma_\tau^{\mathbb{Q}} \equiv \sqrt{Var_t^{\mathbb{Q}}\left[s_{t+\tau}\right]} = \iota' Var_t^{\mathbb{Q}}\left[X_{t+\tau}\right]\iota, \tag{B-2a}$$

$$\eta_\tau^{\mathbb{Q}} \equiv \sqrt{Var_t^{\mathbb{Q}}\left[m_{t+\tau}\right]} = \delta_2' Var_t^{\mathbb{Q}}\left[M_{t+\tau}\right]\delta_2, \tag{B-2b}$$

$$\varrho_\tau^{\mathbb{Q}} \equiv \frac{Cov_t^{\mathbb{Q}}\left[s_{t+\tau}, m_{t+\tau}\right]}{\sigma_\tau^{\mathbb{Q}}\eta_\tau^{\mathbb{Q}}} = \frac{\iota' Cov_t^{\mathbb{Q}}\left[X_{t+\tau}, M_{t+\tau}'\right]\delta_2}{\sigma_\tau^{\mathbb{Q}}\eta_\tau^{\mathbb{Q}}}. \tag{B-2c}$$

and

$$c_\tau \equiv \delta_2' \left[\left(I - e^{-\kappa_{22}^{*}\tau}\right)\theta_2^{*} - \int_0^\tau e^{-\kappa_{22}^{*}(\tau-s)}\widehat{\sigma}_{21}\sigma_{11}'\kappa_{11}^{*\prime -1}\left(I - e^{-\kappa_{11}^{*\prime}(\tau-s)}\right)\iota ds - \chi\widetilde{M}\iota\right], \tag{B-3a}$$

$$d_\tau' \equiv \delta_2' e^{-\kappa_{22}^{*}\tau}, \tag{B-3b}$$

$$e_\tau' \equiv \delta_2' \chi e^{-\kappa_{11}^{*}\tau}. \tag{B-3c}$$

C The FAVAR Analysis

We extract the first three principal components of the macroeconomic variables observed between 1995 and 2022, denoted by x^m, then assume that the factors x^m and the policy rate s^o follow a VAR(1):

$$\begin{bmatrix} x_t^m \\ s_t^o \end{bmatrix} = \begin{bmatrix} \mu^x \\ \mu^s \end{bmatrix} + \rho^m \begin{bmatrix} X_{t-1}^m \\ S_{t-1}^o \end{bmatrix} + \Sigma^m \begin{bmatrix} \epsilon_t^m \\ \epsilon_t^{MP} \end{bmatrix}, \begin{bmatrix} \epsilon_t^m \\ \epsilon_t^{MP} \end{bmatrix} \sim N(0, I), \tag{B-4}$$

where $X_t^m = \left[x_t^m, x_{t-1}^m, \ldots, x_{t-3}^m\right]$ and $S_t^o = \left[s_t^o, s_{t-1}^o, \ldots, s_{t-3}^o\right]$. The monetary policy shock is represented by ϵ_t^{MP}, which is identified following the approach of Bernanke et al. (2005) and Wu and Xia (2016).

The observed macroeconomic variables load on the macroeconomic factors and policy rate as follows:

$$Y_t^m = a_m + b_x x_t^m + b_s s_t^o + \eta_t^m, \eta_t^m \sim N(0, \Omega). \tag{B-5}$$

Note that if $Y_t^{m,i}$ is among the slow-moving variables (i.e., it does not respond to s_t^o), then we set $\widehat{b}_{s,i} = 0$ and regress $Y_t^{m,i}$ on a constant and x_t^m. For other variables, $Y_t^{m,i}$ is regressed on a constant, x_t^m, and s_t^o. In our estimation, we use a large set of observed macroeconomic variables constructed in Koeda et al. (2023), which follows a similar methodology as in McCracken and Ng (2020). See Appendix D for detailed information about the macroeconomic variables we use from the database.

Therefore, the contribution of monetary policy shocks between t_1 and t_2 to an individual economic variable $Y_t^{m,i}$ can be summarized by

$$\sum_{\tau=t_1}^{\max(t,t_2)} \Psi_{t-\tau}^{MP,i} \epsilon_\tau^{MP},$$

where $\Psi_j^{MP,i}$ is the impulse response

$$\Psi_j^{MP,i} = \frac{\partial Y_{t+j}^{m,i}}{\partial \epsilon_t^{MP}} = b_{x,i} \frac{\partial x_{t+j}^m}{\partial \epsilon_t^{MP}} + b_{s,i} \frac{\partial s_{t+j}^o}{\partial \epsilon_t^{MP}},$$

for variable i after j periods in response to a one-unit shock in ϵ_t^{MP}. The derivatives on the right-hand side are the impulse responses from a standard VAR.

D Macroeconomic Variables used in FAVAR

This appendix contains detailed information about the quarterly macroeconomic variables used in the FAVAR analysis, which are constructed in Koeda et al. (2023).

TABLE D-1: Macroeconomic data from Japan

ID	MNEMONIC	DESCRIPTION	Transformation
		Group 1: NIPA	
1	rGDP*	Real Gross Domestic Product (Bil. Chain 2015 Yen)	Δln
2	rC*	Real Household Final Consumption Expenditures (Bil. Chain 2015 Yen)	Δln
3	rI_nonresid*	Real Private Non-Residential Investment (Bil. Chain 2015 Yen)	Δln
4	rI_resid*	Real Private Residential Investment (Bil. Chain 2015 Yen)	Δln
5	rGC*	Real Government Final Consumption Expenditures (Bil. Chain 2015 Yen)	Δln
6	rPI*	Real Public Fixed Capital Formation (Bil. Chain 2015 Yen)	Δln
7	rX*	Real Exports of Goods and Services (Bil. Chain 2015 Yen)	Δln
8	rM*	Real Imports of Goods and Services (Bil. Chain 2015 Yen)	Δln
9	rPC*	Real Private Final Consumption Expeditures (Bil. Chain 2015 Yen)	Δln
10	rC_nonrent*	Real Household Final Consumption Expenditures excl. Imputed Rent (Bil. Chain 2015 Yen)	Δln
11	DrPI_nonresid*	Real Private Inventories (Bil. Chain 2015 Yen)	
12	DrPI*	Real Public Inventories (Bil. Chain 2015 Yen)	
13	rGNI*	Real Gross National Income (Bil. Chain 2015 Yen)	Δln
14	X_GDP*	Exports to GDP (Percent)	
15	M_GDP*	Imports to GDP (Percent)	
16	Dpri*	Private Demand (Bil. Chain 2015 Yen)	Δln
17	Dpub*	Public Demand (Bil. Chain 2015 Yen)	Δln
18	gap*	Output Gap (%)	
		Group 2: Industrial Production	
19	ip*	Industrial Production Index (Mining and Manufacturing, 2020=100)	Δln
20	ip_iron*	Industrial Production Index (Iron and Steel, 2020=100)	Δln
21	ip_manfac*	Industrial Production Index (Manufacturing, 2020=100)	Δln
22	ip_oil*	Industrial Production Index (Petroleum Products, 2020=100)	Δln
23	ip_inventory*	Industorial Inventory Index (Mining and Manufacturing, 2020=100)	Δln
24	ip_final*	Industrial Production Index (Final Demand Goods, 2020=100)	Δln
25	ip_cons*	Industrial Production Index (Consumer Goods, 2020=100)	Δln
26	ip_durable*	Industrial Production Index (Durable Consumer Goods, 2020=100)	Δln
27	ip_nondurable*	Industrial Production Index (Non-Durable Consumer Goods, 2020=100)	Δln
28	ip_manfac_capacity*	Manufacturing Industry Production Capacity Index (2020=100)	Δln
29	manufac_caputil_index*	Manufacturing Industry Operating Ratio Index (2020=100)	Δln
30	index_tertiary*	Industrial Production Index (Tertiary Industry, 2015=100)	Δln
31	capital_ship*	Capital Goods Shipment Index (Excluding Transport Machinery, 2020=100)	Δln
32	capital_supply*	Total Capital Goods Supply Index (Excluding Transport Machinery, 2020=100)	Δln
		Group 3: Employment and Unemployment	
33	ratenewHelpwanted	New Job Openings-to-Applicants Ratio (%)	
34	newHelpwanted*	New Job Openings (Number of Persons)	Δln
35	rateHelpwanted_per*	Active Job Openings-to-Applicants Ratio (Regular Employees, %)	
36	rateHelpwanted*	Job-to-Applicant Ratio (%)	
37	eHelpwanted*	Job Openings (Number of Persons)	Δln
38	hrsworked_5*	Total Actual Working Hours Index - Employment Type (5 Persons or More, 2020=100)	ln
39	hrsworked_30*	Total Actual Working Hours Index - Employment Type (30 Persons or More, 2020=100)	ln
40	emp_manufac*	Employed Person (Manufacturing, 10 Thousand of Persons)	Δln
41	emp_construc*	Employed Person(Construction, 10 Thousand of Persons)	Δln
42	unemploy_rate*	Unemployment Rate (%)	
43	unemploy_rate_male*	Unemployment Rate(Male, %)	
44	unemploy_rate_female*	Unemployment Rate(Female, %)	
45	unemploy*	Unemployed Persons (10 Thousand of Persons)	Δln
46	emp*	Employed Person (10 Thousand of Persons)	Δln
47	nonL*	Non-Labor Force Population (10 Thousand of Persons)	Δln
48	employees*	Total Number of Employees (10 Thousand of Persons)	Δln
49	L*	Labor Force (10 Thousand of Persons)	Δln
50	emp_nonagl*	Employed Person (Non-Agricultural Industries, 10 Thousand of Persons)	Δln
		Group 4: Housing	
51	houst	Housing Starts (Number of Units)	Δln
52	houst_owned	Housing Starts (Ownedn, Number of Units)	Δln
53	houst_rented	Housing Starts (Rented , Number of Units)	Δln
54	houst_forsale	Housing Starts (Built for Sale, Number of Units)	Δln
		Group 5: Inventories, Orders, and Sales	
55	machinery_orders	Machinery Orders (Million of Yen)	Δln
56	retail_sales	Retail Sales	Δln
57	invrate_all	Equipment Investment (Excluding Software, In All Industries, Qoq Growth Rate, %)	
58	profitrate_all	Operating Profit (All Industries, %)	
59	car_sales	New Car Sales (no. of Vehicles)	Δln

Group 6: Prices			
60	deflator*	GDP Deflator (2015=100)	Δln
61	dd_deflator	Domestic Demand Deflator (2015=100)	Δln
62	cpi*	Consumer Price Index (2020=100)	Δln
63	cpi_core*	Consumer Price Index (All Items Excluding Fresh Foods, 2020=100)	Δln
64	cpi_corecore*	Consumer Price Index (All Items Less Food (Excluding Alcohol) and Energy, 2020=100)	Δln
65	cpi_clothes*	Consumer Price Index (Clothing, 2020=100)	Δln
66	cpi_publictransp*	Consumer Price Index (Public Transportation, 2020=100)	Δln
67	cpi_medicines*	Consumer Price Index (Medicines and Health Supplements, 2020=100)	Δln
68	cpi_corecore2*	Consumer Price Index (All Items Less Fresh Food and Energy, 2020=100)	Δln
69	cpi_goods*	Consumer Price Index (Goods, 2020=100)	Δln
70	cpi_durable*	Consumer Price Index (Durable Consumer Goods, 2020=100)	Δln
71	cpi_services*	Consumer Price Index (Services, 2020=100)	Δln
72	cpi_nondurable*	Consumer Price Index (Non-Durable Consumer Goods, 2020=100)	Δln
73	cpi_educ*	Consumer Price Index (Education and Entertainment-Related Services, 2020=100)	Δln
74	cpi_textiles*	Consumer Price Index (Textile Products, 2020=100)	Δln
75	cpi_gas*	Consumer Price Index (Petroleum Products Goods, 2020=100)	Δln
76	cpi_public*	Consumer Price Index (Public Utility Charges, 2020=100)	Δln
77	cpi_medical*	Consumer Price Index (Medical and Welfare-Related Services, 2020=100)	Δln
78	cpi_transportation*	Consumer Price Index (Services Related to Forwarding and Communication, 2020=100)	Δln
79	cpi_tokyo*	Consumer Price Index (All Items, Tokyo, 2020=100)	Δln
80	ppi*	Producer Price Index (2020=100)	Δln
81	ppi_ind*	Producer Price Index (Business Equipment, 2020=100)	ln
82	ppi_power*	Producer Price Index (Electricity, City Gas, and Water Supply, 2020=100)	Δln
83	ppi_minerals*	Producer Price Index (Minerals, 2020=100)	Δln
84	epi*	Export Price Index (Yen-Based, 2020=100)	Δln
85	ipi*	Import Price Index (Yen-Based, 2020=100)	Δln
Group 7: Earnings and Productivity			
86	w_index_regular_manufac*	Wage Index: Monthly Regularly Paid Cash Earnings - Manufacturing Industry (2020=100)	Δln
87	w_index_cash_manufac*	Wage Index: Total Cash Earnings - Manufacturing Industry (2020=100)	Δln
88	cash_earnings_30*	Cash Earnings of Employees (2020=100)	Δln
Group 8: Interest Rates			
89	call	Uncollateralized Call Rate (Overnight,%)	
90	r1y	1Y Government Bond Yield (%)	
91	r5y	5Y Government Bond Yield (%)	
92	r10y	10Y Government Bond Yield (%)	
93	longprime	Long-Term Prime Rate	
94	r1ycall	1Y Government Bond Yield Minus Call Rate	
95	r5ycall	5Y Government Bond Yield Minus Call Rate	
96	r10ycall	10Y Government Bond Yield Minus Call Rate	
Group 9: Money and Credit			
97	mb	Monetary Base (Average Amounts Outstanding, 100 Millions of Yen)	Δln
Group 11: Exchange Rates			
98	yendollar	JPY/USD	Δln
99	neex	Effective Exchange Rate (Nominal, 2020=100)	Δln
100	reex	Effective Exchange Rate (Real, 2020=100)	Δln
Group 12: Other			
101	taido	Consumer Confidence Index	Δln
102	BCDI_manfac	Business Conditions DI (Large Enterprises/Manufacturing)	
103	BCDI_nonmanfac	Business Conditions DI (Large Enterprises/Non-Manufacturing)	
104	BCDI_all	Business Conditions DI (All Industries)	
Group 13: Stock Markets			
105	nikkei225	Nikkei Stock Average	Δln
106	nikkei225_vix	Nikkei 225 VI	Δln
107	stockp	Tokyo Stock Price Index (TOPIX)	Δln
Group 14: Non-Household Balance Sheets			
108	debt_gov*	Total of National Government Debt	Δln