Bank of Japan Working Paper Series

Changes in Perceptions about Monetary Policy: Estimating the Policy Reaction Function Using Market Survey Data

Shunsuke Haba*
shunsuke.haba@boj.or.jp

Ryuichiro Hirano**
ryuuichirou.hirano@boj.or.jp

Yuichiro Ito**
yuuichirou.itou@boj.or.jp

Sohei Kaihatsu**
souhei.kaihatsu@boj.or.jp

No.26-E-5
March 2026

Bank of Japan
2-1-1 Nihonbashi-Hongokucho, Chuo-ku, Tokyo 103-0021, Japan

* Monetary Affairs Department (currently at the Personnel and Corporate Affairs Department)
** Monetary Affairs Department

Changes in Perceptions about Monetary Policy: Estimating the Policy Reaction Function Using Market Survey Data*

Shunsuke Haba† Ryuichiro Hirano‡ Yuichiro Ito§ Sohei Kaihatsu**

March 2026

Abstract

We estimate the policy reaction function of monetary policy as perceived by Japan's market participants, using market survey data. The key findings are as follows. First, consistent with previous research in other economies, the coefficient for inflation rate in the perceived policy reaction function in Japan is almost zero when the nominal interest rate is constrained by the effective lower bound. This coefficient tends to rise during subsequent interest rate hike periods, following changes in central bank policy, suggesting that market participants update their perceptions of monetary policy in response to actual policy changes. Second, although the coefficient for inflation rate generally increases, in the group with long-term inflation expectations deviating downward from the price stability target, it remains low even during recent interest rate hikes, suggesting that this subgroup of market participants may expect an extended period of low interest rates. Third, the market participants who assume a stronger monetary policy response to inflation tend to have more stable long-term inflation expectations around 2%. These results suggest that the perceptions of monetary policy among private agents are state-dependent, and that the macroeconomic stability and the effectiveness of monetary policy may vary over time.

JEL Classification: C32, E43, E52, E58

Keywords: Monetary Policy Rule, Survey Forecasts, Policy Reaction Function

---

* In writing this paper, we received valuable comments from Takuto Arao, Takahiro Minami, Jouchi Nakajima, Koji Nakamura and the BOJ staff members. Any errors remaining in this paper are those of the authors themselves. Additionally, the views expressed herein are those of the authors and do not necessarily reflect the official views of the Bank of Japan.

† Monetary Affairs Department (currently Personnel and Corporate Affairs Department), Bank of Japan (shunsuke.haba@boj.or.jp)

‡ Monetary Affairs Department, Bank of Japan (ryuuichirou.hirano@boj.or.jp)

§ Monetary Affairs Department, Bank of Japan (yuuichirou.itou@boj.or.jp)

** Monetary Affairs Department, Bank of Japan (souhei.kaihatsu@boj.or.jp)

1. Introduction

Since the global financial crisis of 2008, many central banks in advanced economies have enhanced their communication strategies under the constraint of the effective lower bound on nominal interest rates. This reflects the understanding that the effectiveness of monetary policy depends on private agents' expectations of policy responses based on economic and price developments — in other words, on their perceived policy reaction function.[1] In this context, a growing body of research has utilized microdata, such as market surveys, to estimate the policy reaction functions perceived by private agents. These studies examine changes in the coefficients of such functions and analyze their implications for macroeconomic and price stability. However, research focusing specifically on Japan remains limited, and the characteristics of the policy reaction function perceived by private agents is not well understood.

This paper addresses the gap by estimating the perceived policy reaction function in Japan using microdata obtained from a survey targeting market participants. The analysis further investigates the timing of changes in the coefficients of the perceived policy reaction function and evaluates how these changes affect the stability of long-term inflation expectations.

The contributions of this paper can be summarized in three points. First, we use microdata on interest rate forecasts and inflation expectations of market participants in Japan to estimate their perceived policy reaction function and study how its coefficients change over time. Our analysis reveals that, consistent with previous studies on other economies, market participants perceive the coefficient related to inflation (hereafter referred to as the "inflation coefficient") in the policy reaction function to be close to zero when the economy faces the effective lower bound on nominal interest rates. However, during periods of rising interest rates, this coefficient tends to increase following changes in monetary policy. This observation suggests that market participants update their perceptions of monetary policy in response to actual policy changes.

Second, this paper focuses on the heterogeneity of market participants and examines whether the estimated coefficients differ between groups with long-term inflation expectations relatively close to the price stability target of 2 percent and those with expectations that deviate from the target. We estimate the policy reaction function for each group, segmented by the degree of deviation from the price stability target in their long-term inflation expectations, and compare the trajectory of their inflation coefficients. The results indicate that, although the coefficients of the policy reaction function generally increase, those for the group with long-term inflation expectations deviating downward from the price stability target remain low,

[1] Extensive research has explored how private agents' perceptions of the monetary policy reaction function affect macroeconomic stability and the policy effectiveness (see, for example, Clarida et al [2000], Orphanides and Williams [2004], Woodford [2005], Eusepi and Preston [2010], Carvalho and Nechio [2014], Cogley et al. [2015], Coibion et al. [2020]). For a survey, see Blinder et al. [2008].

implying that these participants may still expect an extended period of low interest rates.

Third, this paper is the first to explore the relationship between market participants' perceptions about monetary policy and stability of long-term inflation expectations in Japan. Theoretical literature suggests that when private agents expect the central bank to adjust interest rates in response to economic and price developments, they anticipate those policies to counter economic shocks. As a result, macroeconomic and price fluctuations are mitigated.[2] This mechanism, often referred to as the "automatic stabilizer," is considered beneficial for enhancing the effectiveness of monetary policy, including by reducing the time lag between policy implementation and its effects on the economy (Bauer et al., 2024a). To test this mechanism, we assess the stability of long-term inflation expectations by analyzing its sensitivity to short-term inflation expectations.[3] The findings suggest that an increase in the inflation coefficient in the perceived policy reaction function — a stronger anticipated policy response to inflation — leads to a decline in the sensitivity of long-term inflation expectations to short-term inflation expectations, which implies enhanced stability in long-term expectations around 2%.

These results suggest that private agents' perceptions about monetary policy are state-dependent, and that macroeconomic stability and the effectiveness of monetary policy may vary over time.

(Literature Review)

Many studies in the literature have estimated the policy reaction function, examining the timing of changes in its coefficients and the impact of these changes on financial markets and the real economy. Previous studies have often used consensus data from surveys.[4] Recently, however,

---

[2] Empirical studies, such as Clarida et al. [2000] and Mehra [1999], analyze how private agents' expectations regarding monetary policy responses to economic and price developments affect macroeconomic stability. They compare U.S. monetary policy in the 1970s with that of subsequent years, reporting that a higher inflation coefficient in the policy reaction function helped eliminate self-fulfilling inflationary dynamics and stabilize business cycle fluctuations. From a theoretical perspective, Bullard and Mitra [2002] analyze a model in which expectations are formed through a learning process and demonstrate that a high inflation coefficient in the policy reaction function contributes to economic stability. Similarly, Oda and Nagahata [2005] point out that when monetary policy is conducted appropriately in response to economic and price developments, private agents' expectations formation and subsequent behavior also lead to economic stability.

[3] Bernanke [2007] notes that private agents' perceptions of the policy reaction function are deeply related to the conditions for economic and price stability, emphasizing the importance of private agents' perceptions about monetary policy. He also defines that stability of long-term inflation expectations as the situation where long-term inflation expectations are "insensitive to incoming data," such as shocks to the economy.

[4] There is a large body of research that analyzes policy reaction functions using consensus data from surveys. For example, studies include Batini and Haldane [1999], Gavin and Mandal [2000], Romer and Romer [2002], Gorter, et al. [2008], Bundick [2015], Kim and Pruitt [2017], Jia et al. [2023] for the United States, Sauer and Sturm [2003], Neuenkirch and Siklos [2013] for Europe, and Hofmann and Bogdanova [2012] for cross-country analyses.

there has been a growing trend toward using microdata from surveys or high-frequency financial market data.[5,6]

Among others, Bauer et al. [2024a, 2024b, 2025] employ microdata from the Blue Chip Financial Forecast survey, which is conducted among U.S. experts, and apply cross-sectional regression methods to estimate the perceived policy reaction function. They find that the coefficients of this function tend to change in response to actual policy changes. When these coefficients rise, experts expect stronger monetary policy responses to inflation news, which in turn leads to higher long-term interest rates. Based on these findings, they point out that an increase in the coefficients of the perceived policy reaction function can contribute to greater economic and price stability.[7] Cuciniello [2024] is an example of research that uses high-frequency financial market data to analyze the policy reaction function. He estimates the policy reaction function perceived by market participants using high-frequency data on forward rates derived from OIS and inflation swap rates in the euro area. He finds that when the European Central Bank tightens monetary policy under high inflation, the coefficients tend to rise, and that this increase enhances the stability of long-term inflation expectations. Thus, previous studies have consistently reported that the coefficients of the policy reaction function perceived by private agents tend to change in response to actual policy changes, and that an increase in these coefficients is associated with greater stability in the economy and prices.

In Japan, previous studies have also noted that the coefficients of the policy reaction function perceived by private agents have changed over time, in the face of the effective lower bound on nominal interest rates. Nakazono and Ueda [2013] use data from the "QUICK Monthly Market Survey <Bonds>" for 2004 to 2006, targeting market participants in Japan, to estimate the sensitivity of interest rate forecasts to inflation expectations. They find that sensitivity increased significantly when inflation expectations exceed a threshold near zero percent. They also note that, in any case, sensitivity to nominal interest rates remains low, suggesting that market participants anticipated the continuation of an accommodative monetary environment during that period. Additionally, Fujiwara et al. [2015] use data from the same survey, covering the period from 2004 to 2014, to estimate the policy reaction function of market participants within a panel regression framework. By segmenting the estimation period, they measure changes in the estimated policy reaction function and examine whether the introduction of the price stability target of 2 percent in January 2013 and the "Quantitative and

---

5 Analyses of policy reaction function using microdata from surveys are provided by Mitchell and Pearce [2010], Fendel et al. [2011], Carvalho and Nechio [2014], Carlstrom and Jacobson [2015], Dräger and Lamla [2017], Czudaj [2023], Bauer et al. [2024a, 2024b, 2025], Pflueger [2025], and ECB [2025].

6 Studies that analyze policy reaction functions using high-frequency financial market data include Hamilton et al. [2011], Bocola et al. [2024], Barthélemy [2024], Cuciniello [2024].

7 Empirical analyses that examine how policy reaction functions perceived by private agents are updated in response to policy changes include Cieslak [2018], Schmeling et al. [2022], Bauer and Swanson [2023a, 2023b].

Qualitative Monetary Easing" (QQE) in April 2013 altered market participants' perception of the monetary policy regime. Their analysis finds no notable change in the sensitivity of interest rate forecasts to inflation expectations before and after the implementation of these policies. They conclude that it is difficult to change market participants' perceptions of monetary policy under the constraint of the effective lower bound on nominal interest rates.

Ichiue [2024] is a recent study focusing on Japan that examines the relationship between market participants' perceptions about monetary policy and the stability of economic variables. Using data from the ESP Forecast — a survey conducted among private-sector economists in Japan — spanning the period from 2004 to 2024, he estimates the policy reaction function from the perspective of economic experts and analyzes the relationship between its coefficients and the stability of economic variables, focusing on exchange rates. His results indicate that a rise in the coefficient for inflation rate reduces the influence of U.S. monetary tightening on yen depreciation through exchange rate channels.

This paper contributes to the existing literature in multiple aspects. Specifically, it incorporates the recent period of interest rate hikes into the estimation and adopts a state-space model to allow for an evolution of the coefficients in the policy reaction function over time. Moreover, this paper makes a contribution by analyzing the relationship between shifts in market participants' perceptions about monetary policy and the stability of long-term inflation expectations in Japan, addressing a gap in the existing literature.

The structure of this paper is as follows. Section 2 provides an analysis of changes in market participants' perceptions of the policy reaction function. Section 3 reports the analysis of the impact of changes in perceptions of monetary policy on the stability of long-term inflation expectations. Section 4 concludes.

2. Changes in the Policy Reaction Function Perceived by Market Participants

In this section, we first describe the data and estimation methods used in the analysis. We then examine the estimation results of the policy reaction function as perceived by market participants, focusing on fluctuations in its coefficients and discussing their implications.

2.1 Data

This paper utilizes microdata from the "QUICK Monthly Market Survey <Bonds>", a monthly survey among bond market participants in Japan, conducted by QUICK. The survey targets fund managers, dealers, strategists, economists, and other professionals affiliated with major securities companies, banks, and institutional investors in Japan. The data used in this paper consists of anonymized panel data from respondents and their affiliated institutions, with the number of responses varying across survey rounds but generally around 130. A key feature of the "QUICK Monthly Market Survey <Bonds>" is that it includes survey data from professionals directly involved in the trading operations of the bond market.

The estimation period spans from July 2004 to May 2025, during which data on nominal interest rate forecasts and inflation expectations are available (Table 1). Figures 1 and 2 show the distribution of responses for interest rate forecasts and inflation expectations used in the analysis. It is important to note that the "QUICK Monthly Market Survey <Bonds>" does not include forecasts related to real GDP or production, which are indicators of the real economy. As a result, explanatory variables regarding the supply-demand balance, such as the output gap, cannot be included in the estimation of the policy reaction function.

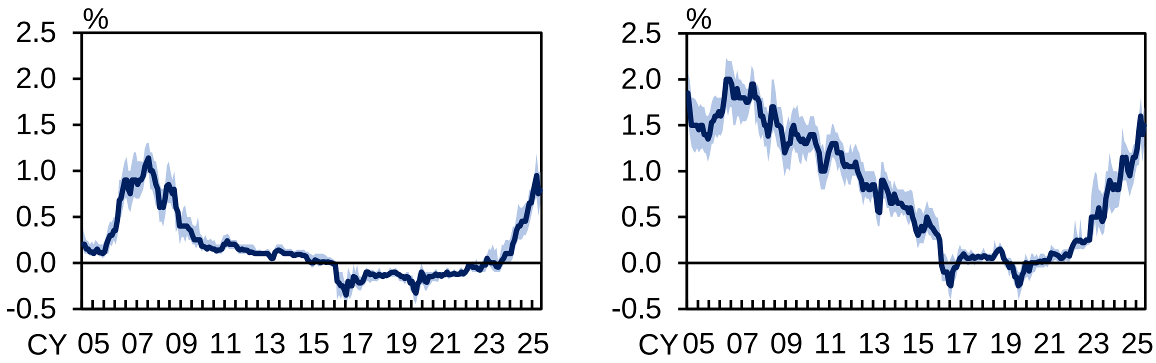
Table 1. Data Description

	Contents
Source	QUICK Monthly Market Survey <Bonds>
Variables	Individual ID, 2-year inflation expectation, 2y-8y inflation expectation, 2-year interest rate forecast, 10-year interest rate forecast
Period	From July 2004 to May 2025
Structure	Unbalanced Panel
# of Forecasters	About 130

Note: 2y-8y inflation expectations are calculated from 2-year ahead and 10-year ahead inflation expectations by authors. The inflation expectation figures exclude the effects of consumption tax hikes. The interest rate forecasts are 3-month ahead forecasts.

Figure 1. Developments in Interest Rate Forecasts

2-year Interest Rate Forecasts | 10-year Interest Rate Forecasts

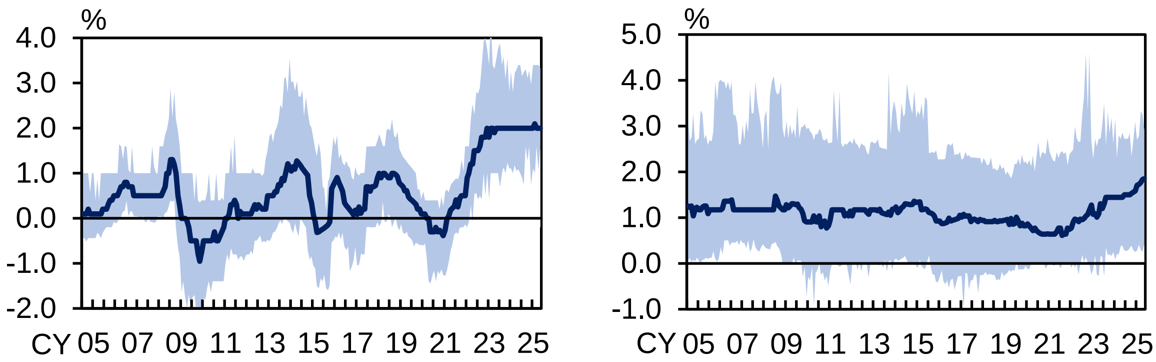


Source: QUICK Monthly Market Survey <Bonds>

Note: The figures are median values, and the shaded areas denote the 95 percentile bands.

Figure 2. Developments in Inflation Expectations

2-year Inflation Expectations | 2y-8y Inflation Expectations



Source: QUICK Monthly Market Survey <Bonds>

Note: The figures are median values, and the shaded areas denote the 95 percentile bands.

2.2 Estimation of the Policy Reaction Function Using Market Survey Data

In this section, we derive the estimation equation for estimating a policy reaction function perceived by market participants, based on microdata from the "QUICK Monthly Market Survey <Bonds>," and outline its key features.

First, we assume that market participants form their policy interest rate forecasts based on a policy reaction function of the Taylor-rule type, as described by Taylor [1993]. It should be noted that, due to data constraints, this policy reaction function does not include variables related to supply-demand balance. Specifically, we consider the following formulation:

$$i_t^S = r_t^* + \bar{\pi}_t + \beta(\pi_t - \pi_t^*) + \varepsilon_t. \tag{1}$$

where the subscript t denotes time, and the variables are as follows: i_t^S, the policy interest rate; r_t^*, the equilibrium real interest rate (natural rate of interest); $\bar{\pi}_t$, the trend inflation rate; π_t, the inflation rate; π_t^*, the central bank's price stability target; and ε_t, the error term.

Next, we assume that market participants update the coefficient β in equation (1) by observing the central bank's policy responses. As suggested by Bauer et al. [2024b] and others, the policy reaction function as perceived by market participant j is expressed as follows, with the updated coefficient $\hat{\beta}_{j,t}$:

$$i_t^S = r_t^* + \bar{\pi}_t + \hat{\beta}_{j,t}(\pi_t - \pi_t^*) + \varepsilon_{j,t}. \tag{2}$$

Then, we consider the relationship between the policy interest rate i_t^S and long-term interest rates. Following Fujiwara et al. [2015] and Ichiue [2024], we decompose the long-term interest rate forecasts for market participant j for h years $\mathrm{E}_{j,t} i_t^h$ into two components: the policy interest rate forecasts for h years ahead $\mathrm{E}_{j,t} i_{t+h}^S$ and expectations about the term premium for h years $\mathrm{E}_{j,t}\mathrm{TP}_t^h$:

$$\mathrm{E}_{j,t} i_t^h = \mathrm{E}_{j,t} i_{t+h}^S + \mathrm{E}_{j,t}\mathrm{TP}_t^h. \tag{3}$$

We assume that market participant j forms their expectations based on equation (2) when forecasting the policy interest rate. Therefore, the h-year ahead policy interest rate forecast by market participant j can be expressed as:

$$\mathrm{E}_{j,t} i_{t+h}^S = \mathrm{E}_{j,t} r_{t+h}^* + \mathrm{E}_{j,t}\bar{\pi}_{t+h} + \hat{\beta}_{j,t}\left(\mathrm{E}_{j,t}\pi_{t+h} - \mathrm{E}_{j,t}\pi_{t+h}^*\right) + \varepsilon_{j,t}. \tag{4}$$

From equations (3) and (4), the long-term interest rate forecast for market participant j can be expressed as:

$$\begin{aligned} \mathrm{E}_{j,t} i_t^h = {} & \mathrm{E}_{j,t} r_{t+h}^* + \mathrm{E}_{j,t}\bar{\pi}_{t+h} + \mathrm{E}_{j,t}\mathrm{TP}_t^h \\ & + \hat{\beta}_{j,t}\left(\mathrm{E}_{j,t}\pi_{t+h} - \mathrm{E}_{j,t}\pi_{t+h}^*\right) + \varepsilon_{j,t}. \end{aligned} \tag{5}$$

Here, we assume that the expectations of market participant j regarding the equilibrium real interest rate, trend inflation rate, and term premium are composed of the common components shared by all market participants ($\mathrm{E}_t r_{t+h}^*$, $\mathrm{E}_t\bar{\pi}_{t+h}$, $\mathrm{E}_t\mathrm{TP}_t^h$, respectively) and individual-specific beliefs for each market participant (r_j^*, $\bar{\pi}_j$, TP_j^h, respectively). Thus, the expectations for market participant j can be expressed as:

$$\mathrm{E}_{j,t} r^*_{t+h} = \mathrm{E}_t r^*_{t+h} + r^*_j, \tag{6}$$

$$\mathrm{E}_{j,t} \bar{\pi}_{t+h} = \mathrm{E}_t \bar{\pi}_{t+h} + \bar{\pi}_j, \tag{7}$$

$$\mathrm{E}_{j,t} \mathrm{TP}^h_t = \mathrm{E}_t \mathrm{TP}^h_t + \mathrm{TP}^h_j. \tag{8}$$

Additionally, we assume that market participants believe the price stability target will remain unchanged in the future, and that the coefficient in the policy reaction function is common across all market participants. This is expressed as:

$$\mathrm{E}_{j,t} \pi^*_{t+h} = \pi^*_t, \tag{9}$$

$$\hat{\beta}_{j,t} = \hat{\beta}_t. \tag{10}$$

Here, we would like to discuss the common component of the trend inflation expectation $\mathrm{E}_t \bar{\pi}_{t+h}$ in equation (7). In standard macroeconomic models, it is often assumed that, under the condition of full credibility of the central bank's price stability target, the trend inflation rate coincides with the price stability target. However, in Japan, there appear to have been periods, such as during past deflationary episodes, when long-term inflation expectations were seemingly not fully anchored to the price stability target. Given this context, directly applying the assumption of full credibility of the central bank's price stability target may not always hold true (Castelnuovo et al., 2003; Gaspar et al., 2010; Ehrmann, 2015; Nishino et al., 2016). Therefore, in this paper, we assume that the common trend inflation expectation for market participants is determined as a weighted average of the price stability target π^*_t and the overall average of long-term inflation expectations for all market participants $\mathrm{E}_t \pi_{t+h}$ as follows:[8]

$$\mathrm{E}_t \bar{\pi}_{t+h} = \omega_t \pi^*_t + (1 - \omega_t) \mathrm{E}_t \pi_{t+h}. \tag{11}$$

where ω_t is a weight that ranges between 0 and 1, representing the degree to which the price stability target influences the trend inflation expectation.

Based on the assumption in equations (6) through (11), the long-term interest rate forecast for market participant j in equation (5) can be expressed as:

[8] In this paper, we assume that when market participants form h-period-ahead forecasts of trend inflation, they have access to the contemporaneous average of inflation expectations $\mathrm{E}_t \pi_{t+h}$.

$$\mathrm{E}_{j,t}i_t^h = \left[\mathrm{E}_t r_{t+h}^* + (1-\omega_t)\mathrm{E}_t\pi_{t+h} + \mathrm{E}_t\mathrm{TP}_t^h - (\hat{\beta}_t - \omega_t)\pi_t^*\right]$$
$$+\hat{\beta}_t\mathrm{E}_{j,t}\pi_{t+h} + \left(r_j^* + \bar{\pi}_j + \mathrm{TP}_j^h\right) + \varepsilon_{j,t}. \quad (12)$$

When equation (12) is transformed into the fixed-effects model representation, it becomes:

$$\mathrm{E}_{j,t}i_t^h = \hat{\alpha}_t + \hat{\beta}_t\mathrm{E}_{j,t}\pi_{t+h} + \delta_j + \varepsilon_{j,t}. \quad (13)$$

This is the estimation equation in this paper, where $\hat{\alpha}_t$ represents the time-varying constant term, and δ_j represents the fixed effect, corresponding to the first and third terms in equation (12), respectively.[9]

Equations (12) and (13) highlight two key properties of the estimation equation in this paper. First, since equations (3) through (13) hold regardless of the length of the interest rate maturity h, the estimation equation in this study ensures that the same $\hat{\beta}_t$ is obtained irrespective of whether a combination of "long-term interest rate and long-term inflation expectations" or "short-term interest rate and short-term inflation expectations" is used. Previous studies that estimate policy reaction functions under low interest rate environments highlight a methodological problem — censoring problem —, where the assumption of i.i.d. (independent and identically distributed) errors in regression analysis is violated due to the inability to observe interest rates below the effective lower bound on nominal interest rates. To address this issue, many studies, such as Fujiwara et al. [2015], Kim and Pruitt [2017], and Ichiue [2024], employ long-term interest rates instead of short-term rates, which are more likely to be constrained by the lower bound on nominal interest rate for extended periods. In fact, interest rate forecasts from the "QUICK Monthly Market Survey <Bonds>" indicate that the 2-year interest rate has shown signs of being constrained by the lower bound since 2009 (Figure 1). Compared to the 10-year interest rate forecast, the 2-year interest rate forecast shows limited capacity for further declines. Therefore, we estimate the policy reaction function, relying on the combination of long-term interest rates and long-term inflation expectations.

Second, because the constant term $\hat{\alpha}_t$ is time-varying and able to capture the influence of π_t^*, the estimation equation used in this study allows the inflation gap $\mathrm{E}_{j,t}\pi_{t+h} - \pi_t^*$ to be replaced with inflation expectations $\mathrm{E}_{j,t}\pi_{t+h}$ without altering the estimated value of $\hat{\beta}_t$. Many previous studies have leveraged this property by employing inflation expectations as the explanatory variable instead of the inflation gap (Fujiwara et al., 2015; Bauer et al., 2024a, 2024b, 2025; Ichiue, 2024). In line with these previous studies, this analysis estimates the policy

[9] See Appendix A for the relationship between the estimation equation and the Taylor principle.

reaction function using inflation expectations as the explanatory variable.

(Derivation of the Long-Term Equilibrium Real Interest Rate Perceived by Market Participants)

Comparing equation (12) with equation (13) reveals that the time-varying constant term $\hat{\alpha}_t$ comprises the equilibrium real interest rate forecasts $\mathrm{E}_t r^*_{t+h}$, the average inflation expectations of market participants $\mathrm{E}_t \pi_{t+h}$, the term premium expectations $\mathrm{E}_t \mathrm{TP}^h_t$, the price stability target π^*_t, and the policy reaction function coefficient $\hat{\beta}_t$. From equations (11) and (12), we have:

$$\begin{aligned} \mathrm{E}_t r^*_{t+h} + \mathrm{E}_t \mathrm{TP}^h_t &= \hat{\alpha}_t + (\hat{\beta}_t - \omega_t)\pi^*_t - (1-\omega_t)\mathrm{E}_t \pi_{t+h} \\ &= \hat{\alpha}_t + \hat{\beta}_t \pi^*_t - \mathrm{E}_t \bar{\pi}_{t+h}. \end{aligned} \tag{14}$$

Then, we assume that the equilibrium real interest rate forecasts $\mathrm{E}_t r^*_{t+h}$ and trend inflation expectations $\mathrm{E}_t \bar{\pi}_{t+h}$ are equal to the currently perceived short-term equilibrium real interest rate (the natural rate of interest) $\mathrm{E}_t r^*_t$ and trend inflation rate $\mathrm{E}_t \bar{\pi}_t$, respectively. Under this assumption, the following relationship can be derived:

$$\mathrm{E}_t r^*_t + \mathrm{E}_t \mathrm{TP}^h_t = \hat{\alpha}_t + \hat{\beta}_t \pi^*_t - \mathrm{E}_t \bar{\pi}_t. \tag{15}$$

The left-hand side of equation (15) represents the short-term equilibrium real interest rate perceived by market participants, along with the h-year term premium. According to previous studies, the sum of the short-term equilibrium real interest rate and the h-year term premium is considered to represent the equilibrium real interest rate corresponding to the h-year interest rate. Therefore, equation (15) provides a formula to derive the long-term equilibrium real interest rate perceived by market participants.[10] On the other hand, the right-hand side consists of the estimated coefficients of the policy reaction function ($\hat{\alpha}_t$, $\hat{\beta}_t$) and the currently perceived trend inflation rate $\mathrm{E}_t \bar{\pi}_t$. Therefore, with assumptions about the latter, the entire right-hand side of equation (15) can be computed. In this way, the estimation results of the fixed-effects model (13) allow us to compute the long-term equilibrium real interest rate perceived by market participants.

[10] The concept of long-term equilibrium real interest rate is based on the approach of estimating the equilibrium yield curve as in Brzoza-Brzezina and Kotłowski [2014]. Following the formulations of Imakubo et al. [2015], Nakajima et al. [2023], Del Negro et al. [2017], and Hatayama and Iwasaki [2024], Nakano et al. [2024] estimate the equilibrium real interest rate at longer maturities as the sum of the short-term equilibrium real interest rate and the trend component of the term premium at the corresponding maturity.

2.3 Estimation Method

This section describes how the policy reaction function — equation (13) in Section 2.2 — is estimated using market survey data. While many related studies use cross-sectional regression for estimation, the "QUICK Monthly Market Survey <Bonds>" used in this paper is an unbalanced panel data set, meaning that there is a certain degree of respondent turnover.[11] As a result, it is likely that the estimated values fluctuate across survey rounds. To mitigate the impact of such fluctuations and assess how monetary policy is perceived by market participants, this paper utilizes a state-space model to estimate the policy reaction function.

The state-space model comprises an observation equation, which represents the policy reaction function as perceived by individual market participants, and a state equation, which describes the dynamics of the estimated coefficients of the policy reaction function.

(Observation Equation)

The observation equation represents the policy reaction function perceived by market participant j, as shown in equation (13):

$$\mathrm{E}_{j,t} i_t^h = \hat{\alpha}_{\mathrm{t}} + \hat{\beta}_t \mathrm{E}_{j,t} \pi_{t+h} + \delta_j + \varepsilon_{j,t}, \qquad \varepsilon_{j,t} \sim N(0, \sigma_\varepsilon^2). \tag{16}$$

where t indicates time, $\mathrm{E}_{j,t} i_t^h$ and $\mathrm{E}_{j,t} \pi_{t+h}$ represent market participant j's 10-year interest rate forecast and 2y-8y inflation expectation, respectively. $\hat{\alpha}_t$ and $\hat{\beta}_t$ are the coefficients, δ_j is the fixed effect, and $\varepsilon_{j,t}$ is the observation noise.

(State Equation)

We assume that the constant term $\hat{\alpha}_t$ and inflation coefficient $\hat{\beta}_t$ follow a random walk process, allowing them to evolve over time:

$$\hat{\alpha}_{\mathrm{t}} = \hat{\alpha}_{\mathrm{t}-1} + \eta_t^\alpha, \qquad \eta_t^\alpha \sim N(0, \sigma_1^2), \tag{17}$$

$$\hat{\beta}_{\mathrm{t}} = \hat{\beta}_{\mathrm{t}-1} + \eta_t^\beta, \qquad \eta_t^\beta \sim N(0, \sigma_2^2). \tag{18}$$

where η_t^α and η_t^β represent the shocks in the random walk process.

(Estimation Method)

We apply the Hamiltonian Monte Carlo method to the state-space model described above in

[11] Around 10 percent of the sample tends to be replaced each time.

order to estimate the posterior distributions of the state variables ($\hat{\alpha}_t$, $\hat{\beta}_t$) and the parameters (σ_ε^2, σ_1^2, σ_2^2).[12] The state variables and parameters to be estimated include the time-varying constant term $\hat{\alpha}_t$, time-varying coefficients $\hat{\beta}_t$, the variance of the observation noise σ_ε^2, and the variances of the shocks in the random walk process (σ_1^2, σ_2^2). The initial values for the time-varying constant term and time-varying coefficients are set as follows: $\hat{\alpha}_1 \sim N(0,2)$, $\hat{\beta}_1 \sim N(0.5,2)$. The prior distributions for the variances of the observation noise and the shocks in the random walk process are set to non-informative prior distributions, $U(0,\infty)$. For estimation, we perform 1,000 samples from four independent chains, treating the first 500 samples as burn-in, and using the last 2,000 samples as the samples from posterior distributions.

The long-term equilibrium real interest rate perceived by market participants is calculated using equation (15). For the trend inflation rate in equation (15), we use the median of the 2y-8y inflation expectation as a proxy variable. The price stability target is assumed to be 1% prior to 2012 and 2% from 2013 onward. This series corresponds to the 10-year equilibrium real interest rate, as the 10-year interest rate forecast and trend inflation rate are used as estimation data.

2.4 Results

This section examines the evolution of the coefficients of the policy reaction function perceived by market participants in Japan, as estimated based on the framework outlined above. By comparing these with the policy events, we discuss the underlying factors behind the changes in the coefficients and examine the trend of the 10-year equilibrium real interest rate as perceived by market participants.

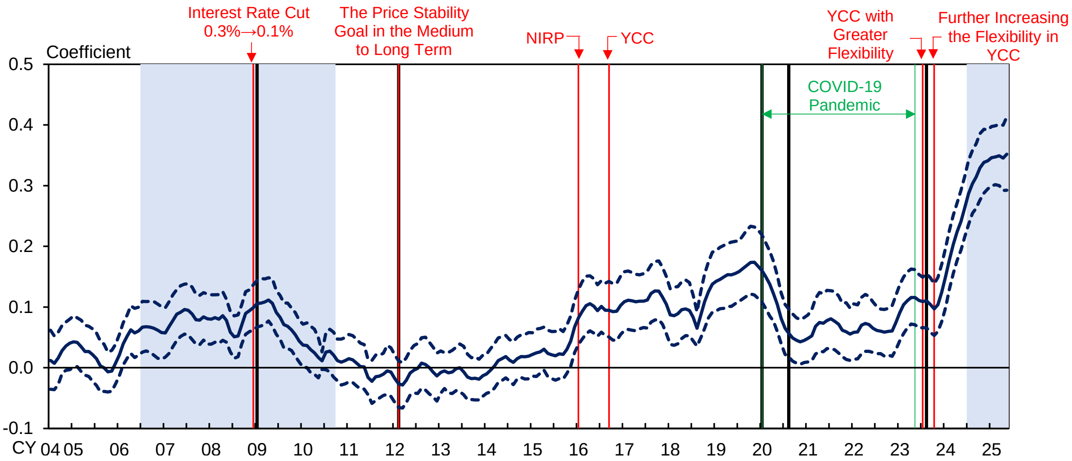
(Market Participants' Perception about Monetary Policy in Japan)

Figure 3 shows the inflation coefficient $\hat{\beta}_t$ of the policy reaction function as perceived by market participants in Japan, together with policy events and the identified structural breakpoints.[13]

[12] The Hamiltonian Monte Carlo method is a type of Markov Monte Carlo method. For details of the estimation method, see Appendix B.

[13] We employ the method of Muggeo [2003], which identifies multiple structural breakpoints in a given time series using a piecewise linear regression model. A distinctive feature of this approach is that it imposes the restriction that the two regression lines estimated for adjacent segments are connected continuously at the breakpoints. In the present analysis, we set the number of breakpoints to five with reference to the BIC and then estimate their locations. See Muggeo [2003, 2008] for details of the estimation method.

Figure 3. Inflation Coefficient in Perceived Policy Reaction Function in Japan ($\hat{\beta}_t$)



Source: QUICK Monthly Market Survey <Bonds>

Note: The Solid and dashed lines represent the posterior median and the 95 percent credible intervals, respectively. The black lines indicate the identified structural breakpoints (following Muggeo [2003]), the red lines denote policy changes by the Bank of Japan, and the shaded areas correspond to periods when positive policy rates were applied.

The Estimation results show that the inflation coefficient $\hat{\beta}_t$ of the policy reaction function as perceived by market participants in Japan, remained close to zero during periods when the nominal interest rate was constrained by the effective lower bound, while it rose during episodes of interest rate hikes and the introduction of the negative interest rate policy.[14]

From the beginning of the sample period until June 2006, the inflation coefficient remained close to zero, indicating that interest rate forecasts were barely responsive to inflation expectations. This may reflect the situation that market participants expected the central bank would be unable to lower interest rates in response to a decline in inflation expectations, due to the effective lower bound on nominal interest rates. It may also reflect the central bank's forward guidance aimed at maintaining accommodative monetary conditions, ensuring a stable rise in prices regardless of short-term economic and price conditions.[15] Similarly, the inflation coefficient initially increased but declined following the rate cut in December 2008, and subsequently remained near zero under the effective lower bound. This suggests that market participants increasingly recognized that either the nominal interest rate was constrained by the

[14] As a robustness check, we conduct two types of analyses. One uses cross-sectional regressions, and the other employed short-term interest rates and short-term inflation expectations as alternative variables. Both analyses yielded broadly similar results. For further details, refer to Appendix C.

[15] From March 2001 to March 2006, the Bank of Japan implemented the "quantitative easing policy," under which (i) the main operating target for money market operation was changed to the outstanding balance of current accounts at the Bank of Japan, (ii) the procedures for money market operations would continue to be in place until the consumer price index (excluding perishables, on a nationwide statistics) would register stably a zero percent or an increase year on year, and (iii) if necessary, the Bank would increase the amount of its outright purchase of long-term government bonds up to the outstanding balance of banknotes issued. For details, see Bank of Japan [2024].

effective lower bound, or an accommodative policy stance would continue for a while. The decline in the inflation coefficient during the COVID-19 period from 2020, while not directly driven by a policy change, may be attributed to market expectations that the nominal interest rate would be constrained by the effective lower bound and that an accommodative monetary environment would remain in place for an extended period of time.

By contrast, during the tightening phase of 2006-2007, the inflation coefficient rose significantly from near zero into positive territory. This can be interpreted as evidence that, once nominal interest rates were no longer constrained by the effective lower bound, market participants became aware of policy rate adjustments in line with inflation conditions, as implied by the Taylor rule. Interestingly, the inflation coefficient also increased at the time of the introduction of the negative interest rate policy in January 2016.[16] One possible interpretation is that market participants began to expect policy rate adjustments consistent with the Taylor rule, given the possibility of further cuts into negative territory. This view is consistent with the empirical analyses of Ueno [2017] and Suganuma and Yamada [2017], which demonstrate that the introduction of the negative interest rate policy in Japan shifted market participants' perception of the lower bound on nominal interest rates from zero to negative values.

In the most recent tightening phase, the inflation coefficient rose markedly following the "Conducting Yield Curve Control (YCC) with Greater Flexibility"[17] in July 2023 and the "Further Increasing the Flexibility in the Conduct of YCC" in October 2023, suggesting that market participants became increasingly aware of the normalization of monetary policy.[18] Figure 4 compares the evolution of the inflation coefficient with that of long-term inflation expectations. In Japan, inflation expectations began rising around 2021, whereas the inflation coefficient only started to rise after the implementation of more flexible YCC measures in 2023. This finding indicates that market participants are likely to update their perceptions of monetary policy in reaction to actual policy changes, consistent with studies analyzing other economies

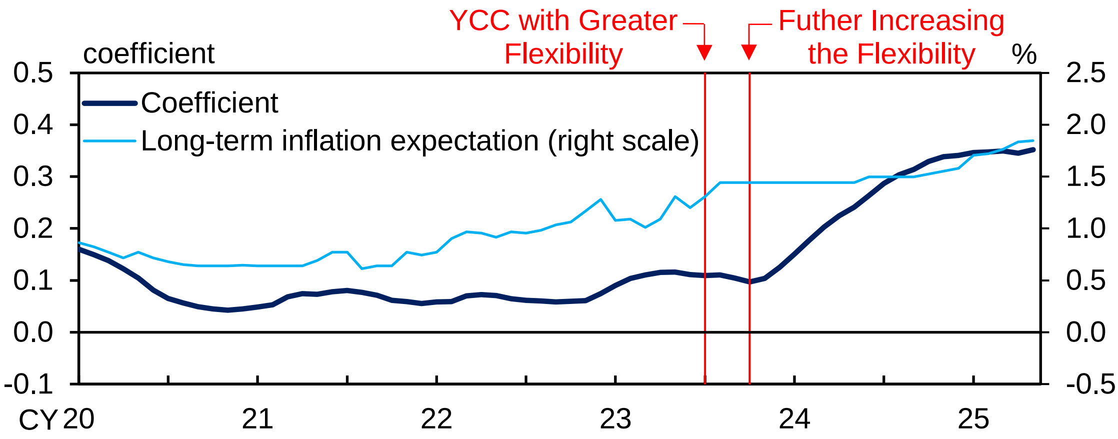
[16] For detail on Japan's negative interest rate policy, see Haba et al. [2025].

[17] In September 2016, the Bank of Japan introduced the framework of yield curve control (YCC) with a view to appropriately controlling nominal interest rates at suitable levels, taking into account not only the effects but also the side effects of prolonged monetary easing. However, since 2022, when inflation and inflation expectations began to rise, concerns have been raised that this policy might impair the functioning of the government bond market (Bank of Japan Financial Markets Department, 2023; Fukuma et al., 2024). Against this background, in July 2023 the Bank of Japan decided to introduce "Conducting YCC with Greater Flexibility" in order to mitigate the impact of YCC on the functioning of the government bond market. While a strict upper limit remains in place, the framework was modified to allow for a certain degree of increase in long-term interest rates.

[18] The Bank of Japan decided to introduce "Further Increasing the Flexibility in the Conduct of YCC" in order to enhance flexibility of conducting YCC by changing the strict capping to the "upper bound as a reference" because the Bank considered the strictly capping long-term interest rates would have strong positive effects, but could also entail large side effects.

(Bauer et al., 2024a, 2024b, 2025; Cuciniello, 2024; Bocola et al., 2024; Pflueger, 2025).

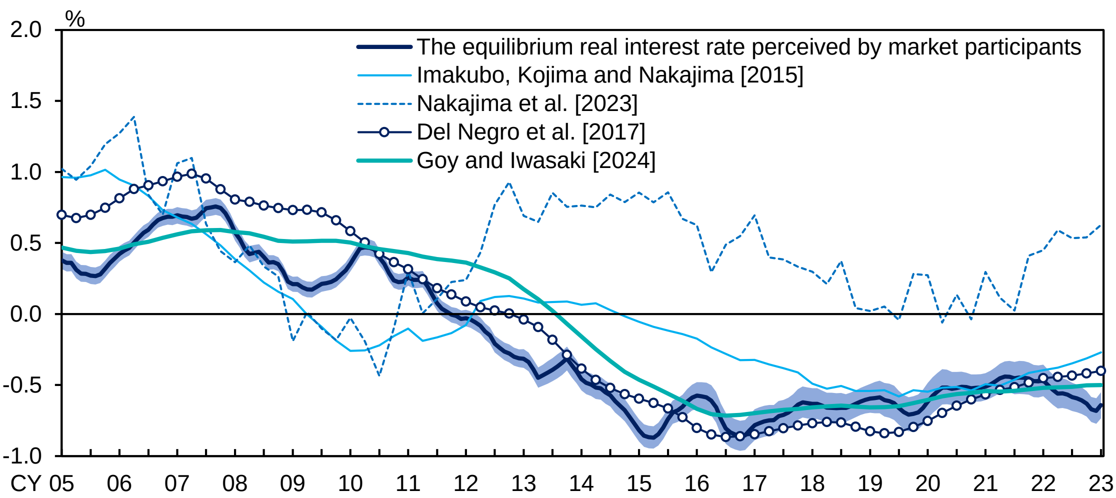
Figure 4. Long-Term Inflation Expectations and $\hat{\beta}_t$



Source: QUICK Monthly Market Survey <Bonds>

Note: The figures for "Coefficient" indicate the inflation coefficient in perceived policy reaction function by market participants. The figures for "Long-term inflation expectations" show the median value of 2y-8y inflation expectations in QUICK Monthly Market Survey <Bond>.

Figure 5. The Market-Perceived 10-Year Equilibrium Real Interest Rate in Japan



Sources: Bank of Japan; Ministry of Finance, Ministry of Health, Labour and Welfare; Ministry of Internal Affairs and Communications; Cabinet Office; Bloomberg; Consensus Economics "Consensus Forecast"; QUICK Monthly Market Survey <Bonds>

Note: The equilibrium real interest rate perceived by market participants is measured as the 6-month backward moving average of the posterior median estimated from equation (15). The shaded area represents the 95 percent credible interval. The other lines show estimates of Japan's 10-year equilibrium real interest rates from various models.

(The Market-Perceived Equilibrium Real Interest Rate in Japan)

A comparison of the estimated 10-year equilibrium real interest rate perceived by market participants in Japan and estimates from previous studies reveals that, despite differences in estimation methods, the values generally fall within the range suggested in the literature (Figure 5). The evolution of the perceived 10-year equilibrium real interest rate indicates a gradual decline until around 2015, amid a prolonged low interest rate environment following the global financial crisis, eventually reaching nearly −1 percent. Thereafter, as monetary easing continued, the perceived equilibrium real rate remained at a low level.

2.5 Heterogeneity in Policy Reaction Functions Perceived by Market Participants

So far, the analysis has assumed that market participants are homogenous. In this section, we relax this assumption and explore the possibility of heterogeneity in their perceptions.

We specifically examine whether the estimated coefficients of the policy reaction function differ between the group with long-term inflation expectations close to the 2 percent price stability target and the group deviating from the target.[19] Participants are classified into two groups based on the "average deviation of long-term inflation expectations from the price stability target": those with deviations smaller than the median are considered as having expectations close to the target, while those with larger deviations belong to the group with expectations deviating from the target.[20] Among the group close to the target, the median of long-term inflation expectations has recently converged toward 2 percent. In contrast, expectations for the group deviating from the target have remained steady around 1 percent (Figure 6). The current distribution of long-term inflation expectations reveals that the group close to the target is concentrated around 2 percent, while the group deviating from the target exhibits a flatter distribution shifted toward lower inflation (Figure 7).

Examining the inflation coefficients of the perceived policy reaction function for each group, we observe that the coefficient has recently risen markedly in the group close to the price stability target, while the increase remains modest in the group deviating from the target (Figure 8). This suggests that participants with expectations near the target anticipate policy responses aligned with inflation expectations, as implied by the Taylor rule. By contrast, those in the group with expectations deviating from the target may still expect the continuation of low interest rates.[21]

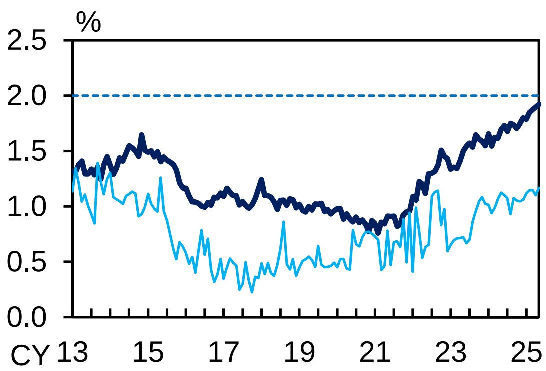
[19] The approach of dividing the sample and comparing the coefficients of the policy reaction function to examine whether there are differences in perceptions across groups is based on Bauer et al. [2024a].

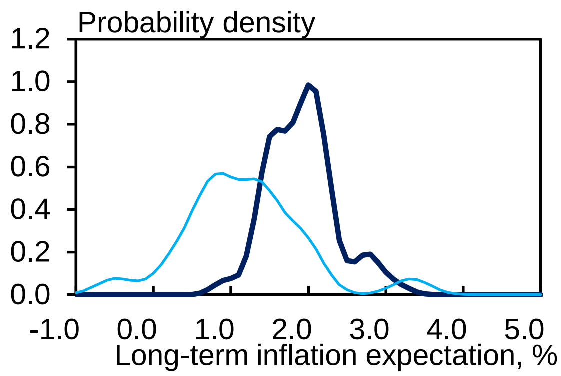
[20] The "average deviation of long-term inflation expectations from the price stability target" is defined as follows. Let $\mathrm{E}_{j,t}|\hat{\pi}_{t+h}|$ denote the absolute difference between market participant j's long-term inflation expectation at time t and the price stability target, and let $\mathrm{E}_t|\hat{\pi}_{t+h}|$ denote the cross-sectional average of $\mathrm{E}_{j,t}|\hat{\pi}_{t+h}|$. Then, participant j's "average deviation of long-term inflation expectations from the price stability target" is defined as the time-series average of $\mathrm{E}_{j,t}|\hat{\pi}_{t+h}|/\mathrm{E}_t|\hat{\pi}_{t+h}|$.

[21] There were no significant differences in the estimated values of the perceived 10-year equilibrium real interest rate across groups. This suggests that while there may be heterogeneity in market participants' perceptions of monetary policy, it is primarily reflected in the inflation coefficient of the policy reaction function.

Figure 6. Developments in Inflation Expectations

Figure 7. Distributions of Inflation Expectations





A group with long-term inflation expectations close to the price stability target
A group with long-term inflation expectations deviating from the price stability target
Price stability target

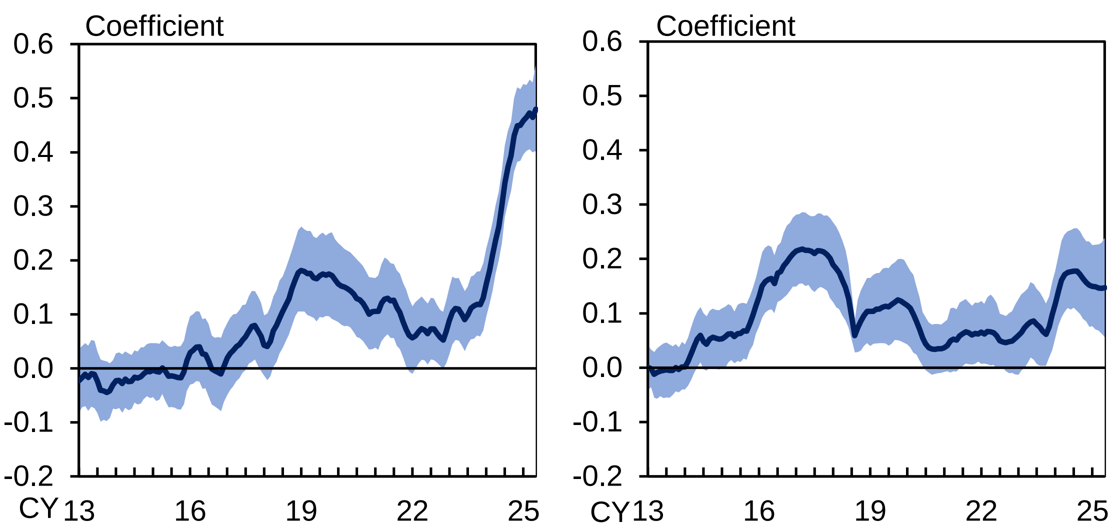
Source: QUICK Monthly Market Survey <Bonds>

Note: The distributions are as of May 2025.

Figure 8. Inflation Coefficient ($\hat{\beta}_t$) Developments by Group

Group with Long-Term Inflation Expectations Close to the Price Stability Target

Group with Long-Term Inflation Expectations Deviating from the Price Stability Target



Source: QUICK Monthly Market Survey <Bonds>

Note: The shaded areas denote the 95 percent credible intervals.

3. How Changes in Market Participants' Perceptions Affect the Stability of Long-Term Inflation Expectations

In the previous section, we traced the developments in market participants' perceptions of monetary policy in Japan by examining changes in the coefficients of the perceived policy reaction function. What implications would a shift in market expectations regarding monetary policy have for the real economy and price dynamics?

Previous studies suggest that a higher inflation coefficient in the perceived policy reaction function causes financial market variables and private agents' expectations to shift toward a macroeconomic stabilization. This occurs because a positive inflation coefficient leads private agents to expect central bank policy rate adjustments in response to shocks, limiting the impact of these shocks on their economic and price expectations. In this context, Cuciniello [2024] uses high-frequency financial market data, such as forward rates derived from OIS and inflation swap rates in Europe, to estimate the policy reaction function as perceived by market participants. He highlights that a rise in the inflation coefficient leads to improved stability of long-term inflation expectations.

In this section, we clarify the concept of the stability of long-term inflation expectations, and, drawing on the analytical framework of Cuciniello [2024], empirically analyze the relationship between the inflation coefficient $\hat{\beta}_t$ of the perceived policy reaction function and the stability of long-term inflation expectations in Japan.

3.1. How to Assess the Stability of Long-Term Inflation Expectations

Long-term inflation expectations are typically considered stable when they are insensitive to economic shocks (Bernanke, 2007). Building on this concept, empirical studies often evaluate the stability of long-term inflation expectations by observing their responsiveness to short-term inflation expectations or perceived inflation. If this responsiveness is found to be low, it suggests that long-term expectations are unaffected by temporary shocks and can thus be considered "well-anchored" (Levin et al., 2004; Kumar et al., 2015; Carvalho et al., 2023; Hogen and Okuma, 2025).

Following this interpretation, we consider a decline in the responsiveness of long-term inflation expectations to short-term inflation expectations as evidence of increased stability.

3.2. Estimation Method

To examine whether the stability of long-term inflation expectations improves when $\hat{\beta}_t$ increases, we conduct a panel regression analysis using data from the "QUICK Monthly Market Survey <Bonds>," following the specification proposed by Cuciniello [2024]. The specific formulations are as follows:

$$\Delta \mathrm{E}_{j,t}\pi_t^L = \theta \Delta \mathrm{E}_{j,t}\pi_t^S + \kappa\left(\Delta \mathrm{E}_{j,t}\pi_t^S * \hat{\beta}_{t-1}\right) + \omega\hat{\beta}_{t-1} + \mu_j + o_{j,t}, \tag{19}$$

$$\Delta \mathrm{E}_{j,t}\pi_t^L = \theta \Delta \mathrm{E}_{j,t}\pi_t^S + \kappa\left(\Delta \mathrm{E}_{j,t}\pi_t^S * \hat{\beta}_{t-1}\right) + \nu_t + \mu_j + o_{j,t}. \tag{20}$$

where $\Delta \mathrm{E}_{j,t}\pi_t^L$ denotes the change in participant j's 2y-8y inflation expectation between period $t-1$ and period t, and $\Delta \mathrm{E}_{j,t}\pi_t^S$ denotes the change in the 2-year inflation expectation. $\hat{\beta}_{t-1}$ represents the inflation coefficient of the perceived policy reaction function at period $t-1$. μ_j denotes fixed effects, and $o_{j,t}$ is the error term. Equation (20) is a specification in which the term of inflation coefficient $\omega\hat{\beta}_{t-1}$ in equation (19) is replaced with time fixed effects ν_t, thereby attempting to control for macroeconomic factors other than the inflation coefficient. The estimation period covers August 2004 to May 2025.

The stability of long-term inflation expectations is captured by the coefficients θ and κ in equations (19) and (20). The coefficient θ represents the sensitivity of long-term inflation expectations to short-term inflation expectations when $\hat{\beta}_{t-1}$ is zero. Given that many studies on Japan report adaptive inflation expectation formation, θ is expected to be positive.[22] Meanwhile, κ measures the additional change in the sensitivity of long-term expectations to short-term expectations when the perceived coefficient $\hat{\beta}_{t-1}$ increases by one unit. In this specification, if κ takes a negative value while $\hat{\beta}_{t-1}$ is positive, the sensitivity of long-term expectations to short-term expectations may decline. Taking into account the discussion in the previous section, this framework enables us to examine whether the stability of long-term inflation expectations improves when $\hat{\beta}_{t-1}$ changes. Given that the estimated values of $\hat{\beta}_t$ have been non-negative throughout the sample period, the stability of long-term inflation expectations is expected to improve as $\hat{\beta}_{t-1}$ increases, provided that θ is positive and κ is negative.

3.3. Results

The estimation results of equation (19) and (20) show that, in both specifications, the coefficient θ on short-term inflation expectations is statistically significant and positive, while the coefficient κ on the interaction between short-term inflation expectations and the perceived inflation coefficient $\hat{\beta}_{t-1}$ is significantly negative (Table 2). The finding that θ is significantly positive indicates that long-term inflation expectations tend to move in tandem

[22] For the adaptive formation of inflation expectations in Japan, see Bank of Japan [2016, 2021, 2024], Kitamura and Tanaka [2019], Maruyama and Suganuma [2020], Ikeda et al. [2022], Fukunaga et al. [2024], Hogen and Okuma [2025], and Fujii et al. [2025].

with short-term expectations, reflecting the adaptive nature of expectation formation in Japan.

Furthermore, the result that κ is significantly negative implies that an increase in the inflation coefficient of the perceived policy reaction function reduces the sensitivity of long-term inflation expectations to short-term expectations. As discussed above, this suggests an improvement in the stability of long-term inflation expectations.

It should be noted that the interpretation of the increasing stability of long-term inflation expectations in Japan may vary over time. Specifically, during periods of deflation, an increase in the stability of long-term inflation expectations at a level below the price stability target suggests that market participants believed at that time that long-term inflation expectations would remain low. This perception of market participants may reflect the entrenchment during the so-called deflationary period of the behavior and mindset based on the assumption that wages and prices would not increase easily.

On the other hand, in the most recent phase, the increase in the stability of long-term inflation expectations at a level relatively close to the price stability target, as demonstrated in the study by Cuciniello [2024] focusing on Europe, suggests the possibility that long-term inflation expectations are becoming less influenced by short-term inflation expectations, and that the anchoring to the price stability target is strengthening. Furthermore, as shown in Figure 8, given that there has been a relative increase in the inflation coefficient of market participants whose long-term inflation expectations are close to the 2% price stability target, it can be argued that market participants who anticipate a stronger monetary policy response to the inflation rate tend to have more stable long-term inflation expectations around 2%. However, this analysis does not examine the exact mechanism behind how an increase in the inflation coefficient influences the stability of long-term inflation expectations.

Table 2. Results of the Analyses for the Stability of Long-Term Inflation Expectations

		Dependent variable：Change in long-term inflation expectations (month-on-month, % points)	
		Equation (19)	Equation (20)
Change in short-term inflation expectations (month-on-month, % points)	θ	0.41***	0.43***
		(0.06)	(0.06)
〃 $\times \hat{\beta}_{t-1}$	κ	−0.90*	−0.86*
		(0.48)	(0.49)
$\hat{\beta}_{t-1}$	ω	0.11***	
		(0.03)	
Fixed effect		YES	YES
Time fixed effect		NO	YES
Adj. R^2		0.06	0.08
# of Observations		27,529	
Estimation period		From August 2004 to May 2025	

Source: QUICK Monthly Market Survey <Bonds>

Note: *** and * denote significance at the 1 and 10 percent levels, respectively. Robust standard errors clustered by forecasters are reported in parentheses.

4. Conclusion

This paper applies a state-space modeling framework to survey-based microdata from market participants in Japan to estimate their perceived policy reaction function. We further analyze the dynamics of its coefficients over time and examine the relationship between these coefficients and the stability of long-term inflation expectations.

The main findings of this paper can be summarized as follows. First, while the coefficients of the policy reaction function remained close to zero in the economy facing the effective lower bound on nominal interest rates, they tended to rise during tightening phases following actual policy changes. This finding aligns with the previous studies on other countries, indicating that private agents tend to update their perceptions of the policy reaction function in response to actual policy changes. Second, the analysis of heterogeneity in perceptions of the policy reaction function reveals that while the coefficients have risen overall in recent times, they remain low for the group whose long-term inflation expectations deviate from the price stability target. Third, the results indicate that market participants who assume a stronger monetary policy response to inflation tend to have stable long-term inflation expectations around 2%. This finding suggests that perceptions about monetary policy among private agents are state-dependent, and that the macroeconomic stability and the effectiveness of monetary policy may vary over time.

Finally, we note several issues that remain for future research. First, while this paper has focused on market participants, it is also important to consider how households and firms perceive monetary policy responses, given their relevance to the real economy.[23] Second, in situations where private agents update their perceptions of the policy reaction function based on their observations of central bank actions, it becomes crucial to evaluate which communication strategies are most effective.[24] In order to evaluate the effectiveness of monetary policy, deepening our understanding of the characteristics of private agents' perceptions is considered valuable.

[23] Bernanke [2010] emphasizes the importance of enhancing businesses' and households' understanding of monetary policy conduct, stating:

"Improving the public's understanding of the central bank's policy strategy reduces economic and financial uncertainty and helps households and firms make more-informed decisions. Moreover, clarity about goals and strategies can help anchor the public's longer-term inflation expectations more firmly and thereby bolsters the central bank's ability to respond forcefully to adverse shocks."

[24] Bauer et al. [2024b] discuss the role of central bank communication strategies in shaping the perception of monetary policy by private agents, stating:

"This opens the door for important additional research, addressing such questions as how central bank communication shapes perceptions about the monetary policy strategy and how optimal monetary policy should account for shifting perceptions in seeking to stabilize inflation and employment."

Reference

Ascari, G. and A. M. Sbordone [2014], "The Macroeconomics of Trend Inflation," *Journal of Economic Literature*, 52(3), 679-739.

Bank of Japan [2016], *Comprehensive Assessment: Developments in Economic Activity and Prices as well as Policy Effects since the Introduction of Quantitative and Qualitative Monetary Easing (QQE)*.

Bank of Japan [2021], *Assessment for Further Effective and Sustainable Monetary Easing*.

Bank of Japan [2024], *Review of Monetary Policy from a Broad Perspective*.

Bank of Japan Financial Markets Department [2023], "Bond Market Survey, Results of Special Survey (November 2023)," Bond Market Survey, December. 1, 2023.

Barthélemy, J. [2024], "Market Perception of Monetary Policy Responsiveness," Eco Notepad, Banque de France, 359.

Batini, N. and A. G. Haldane [1999], "Forward-Looking Rules for Monetary Policy," In *Monetary Policy Rules*, 157-202.

Bauer, M. D., C. E. Pflueger, and A. Sunderam [2024a], "Changing Perceptions and Post-Pandemic Monetary Policy," *Proceedings of 2024 Jackson Hole Economic Policy Symposium*, 285-336.

Bauer, M. D., C. E. Pflueger, and A. Sunderam [2024b], "Perceptions about Monetary Policy," *The Quarterly Journal of Economics*, 139(4), 2227–2278.

Bauer, M. D., C. E. Pflueger, and A. Sunderam [2025], "Current Perceptions about Monetary Policy," *FRBSF Economic Letter*, February 24, 2025.

Bauer, M. D. and E. T. Swanson [2023a], "An Alternative Explanation for the 'Fed Information Effect'," *American Economic Review*, 113(3), 664–700.

Bauer, M. D. and E. T. Swanson [2023b], "A Reassessment of Monetary Policy Surprises and High-Frequency Identification," *NBER Macroeconomics Annual*, 37, 87–155.

Baydin, A. G., B. A. Pearlmutter, A. A. Radul, and J. M. Siskind [2018], "Automatic Differentiation in Machine Learning: A Survey," *Journal of Machine Learning Research*, 18, 1-43.

Bernanke, B. S. [2007], "Inflation Expectations and Inflation Forecasting," Speech at the Monetary Economics Workshop of the National Bureau of Economic Research Summer Institute, Cambridge, MA, July 10.

Bernanke, B. S. [2010], "Monetary Policy Objectives and Tools in a Low-Inflation Environment," Remarks at "Revisiting Monetary Policy in a Low-Inflation Environment" a Conference Sponsored by the Federal Reserve Bank of Boston, Boston, MA, October 15.

Blinder, A. S., M. Ehrmann, M. Fratzscher, J. de Haan, and D. Jansen [2008], "Central Bank Communication and Monetary Policy: A Survey of Theory and Evidence," *Journal of Economic Literature*, 46(4), 910–945.

Bocola, L., A. Dovis, K. Jørgensen, and R. Kirpalani [2024], "Bond Market View of the Fed," NBER Working Papers, 32620.

Brzoza-Brzezina, M. and J. Kotłowski [2014], "Measuring the Natural Yield Curve," *Applied Economics*, 46(17), 2052-2065.

Bullard, J. and K. Mitra [2002], "Learning about Monetary Policy Rules," *Journal of Monetary Economics*, 49, 1105-1129.

Bundick, B. [2015], "Estimating the Monetary Policy Rule Perceived by Forecasters," *Federal Reserve Bank of Kansas City, Economic Review*, 100(4), 33–49.

Carlstrom, C. T. and M. Jacobson [2015], "Do forecasters agree on a Taylor rule?" *Federal Reserve Bank of Cleveland, Economic Commentary,* 2015-10.

Carvalho, C., S. Eusepi, E. Moench, and B. Preston [2023], "Anchored Inflation Expectations," *American Economic Journal: Macroeconomics*, 15(1), 1-47.

Carvalho, C. and F. Nechio [2014], "Do People Understand Monetary Policy?" *Journal of Monetary Economics*, 66, 108–123.

Castelnuovo, E., S. Nicoletti-Altimari, and D. Rodríguez-Palenzuela [2003], "Definition of Price Stability, Range and Point Inflation Targets: The Anchoring of Long-Term Inflation Expectations," ECB Working Paper Series, 273.

Cieslak, A. [2018], "Short-Rate Expectations and Unexpected Returns in Treasury Bonds," *The Review of Financial Studies*, 31(9), 3265–3306.

Clarida, R., J. Galí, and M. Gertler [2000], "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," *The Quarterly Journal of Economics*, 115(1), 147–180.

Cogley, T., C. Matthes, and A. M. Sbordone [2015], "Optimized Taylor Rules for Disinflation When Agents Are Learning," *Journal of Monetary Economics*, 72, 131–147.

Coibion, O., Y. Gorodnichenko, S. Kumar, and M. Pedemonte [2020], "Inflation Expectations as a Policy Tool?" *Journal of International Economics*, 124, 103297.

Cuciniello, V. [2024], "Market Perceptions, Monetary Policy, and Credibility," Banca D'Italia Working Papers, 1449.

Czudaj, R. L. [2023], "Are the Forecasts of Professionals Compatible with the Taylor Rule? Evidence from the Euro Area," *Macroeconomic Dynamics*, 27(3), 698-717.

Del Negro, M., D. Giannone, M. P. Giannoni, and A. Tambalotti [2017], "Safety, Liquidity, and the Natural Rate of Interest," *Brookings Papers on Economic Activity*, Spring 2017, 235-316.

Dräger, L. and M. J. Lamla [2017], "Explaining Disagreement on Interest Rates in a Taylor-Rule Setting," *The Scandinavian Journal of Economics*, 119(4), 987-1009.

Duane, S., A. D. Kennedy, B. J. Pendleton, and D. Roweth [1987], "Hybrid Monte Carlo," *Physics Letters B*, 195(2), 216-222.

Ehrmann, M. [2015], "Targeting Inflation from Below: How Do Inflation Expectations Behave?" *International Journal of Central Banking*, 11(S1), 213-249.

European Central Bank [2025], "Report on Monetary Policy Tools, Strategy and Communication," Occasional Paper Series, European Central Bank.

Eusepi, S. and B. Preston [2010], "Central Bank Communication and Expectations Stabilization," *American Economic Journal: Macroeconomics*, 2(3), 235–271.

Fendel, R., M. Frenkel, and J. Rülke [2011], "'Ex-Ante' Taylor Rules – Newly Discovered Evidence from the G7 Countries," *Journal of Macroeconomics*, 33, 224-232.

Fujii, G., S. Nakano, and K. Takatomi [2025], " Households' Medium- to Long-Term Inflation Expectations Formation: The Role of Past Experience and Inflation Regimes," Bank of Japan Working Paper Series, 25-E-6.

Fujiwara, I., Y. Nakazono, and K. Ueda [2015], "Policy Regime Change against Chronic Deflation? Policy Option under a Long-Term Liquidity Trap," *Journal of the Japanese and International Economies*, 37, 59-81.

Fukuma, N., T. Kitamura, K. Maehashi, N. Matsuda, K. Takemura, and K. Watanabe [2024], "The Impact of Quantitative and Qualitative Easing and Yield Curve Control on the Functioning of the Japanese Government Bond Market," Bank of Japan Working Paper Series, 24-E-9.

Fukunaga, I., Y. Hogen, and Y. Ueno [2024], "Japan's Economy and Prices over the Past 25 Years: Past Discussions and Recent Issues," Bank of Japan Working Paper Series, 24-E-14.

Gaspar, V., F. Smets, and D. Vestin [2010], "Inflation Expectations, Adaptive Learning and Optimal Monetary Policy," *Handbook of Monetary Economics*, 3, 1055–1095.

Gavin, W. T. and R. J. Mandal [2000], "Forecasting Inflation and Growth: Do Private Forecasts Match Those of Policymakers?" Federal Reserve Bank of St. Louis Working Papers, 2000-026A.

Gorter, J., J. Jacobs, and J. de Haan [2008], "Taylor Rules for the ECB using Expectations Data," *The Scandinavian Journal of Economics*, 110(3), 473-488.

Goy, G. and Y. Iwasaki [2024], "From the Natural Rate towards a Natural Curve: A First Step to Benchmarking the Term Structure," mimeo.

Haba, S., Y. Ito, and Y. Kasai [2025], "The Impact of Negative Interest Rate Policy on Interest Rate Formation and Lending," Bank of Japan Working Paper Series, 25-E-1.

Hamilton, J. D., S. Pruitt, and S. Borger [2011], "Estimating the Market-Perceived Monetary Policy Rule," *American Economic Journal: Macroeconomics*, 3(3), 1–28.

Hatayama, Y. and Y. Iwasaki [2024], "Estimating the Natural Yield Curve in Japan Using a VAR with Common Trend," Bank of Japan Working Paper Series, 24-E-17.

Hoffman, M. D. and A. Gelman [2014], "The No-U-Turn Sampler: Adaptive Setting Path Lengths in Hamiltonian Monte Carlo," *Journal of Machine Learning Research*, 15, 1593-1623.

Hofmann, B. and B. Bogdanova [2012], "Taylor Rules and Monetary Policy: A Global 'Great Deviation'?" *BIS Quarterly Review*, September 2012, 37-49.

Hogen, Y., and R. Okuma [2025], "The Anchoring of Inflation Expectations in Japan: A Learning-Approach Perspective," *Japan and the World Economy*, 73, 101293.

Ichiue, H. [2024], "The Expected Sensitivity of the Long-Term Yield to Macroeconomic Conditions," Presentation at Summer Workshop on Economic Theory 2024, Sapporo, Japan, 10 August 2024.

Ikeda, S., H. Inatsugu, Y. Kishaba, T. Kondo, K. Sakura, K. Takatomi, T. Nakazawa, and K. Yamada [2022], "Inflation in Japan: Changes during the Pandemic and Issues for the Future," Bank of Japan Working Paper Series, 22-E-18.

Imakubo, K., H. Kojima, and J. Nakajima [2015], "The Natural Yield Curve: Its Concept and Measurement," Bank of Japan Working Paper Series, 15-E-5.

Jia, P., H. Shen, and S. Zheng [2023], "Monetary Policy Rules and Opinionated Markets," *Economics Letters*, 223, 110995.

Kim J. and S. Pruitt [2017], "Estimating Monetary Policy Rules When Nominal Interest Rates Are Stuck at Zero," *Journal of Money, Credit and Banking*, 49(4), 585-602.

Kitamura, T. and M. Tanaka [2019], " Firms' Inflation Expectations under Rational Inattention and Sticky Information: An Analysis with a Small-Scale Macroeconomic Model," Bank of Japan Working Paper Series, 19-E-16.

Kumar, S., O. Coibion, H. Afrouzi, and Y. Gorodnichenko [2015], "Inflation Targeting Does Not Anchor Inflation Expectations: Evidence from Firms in New Zealand," *Brookings Papers on Economic Activity*, Fall 2015, 151-208.

Levin, A. T., F. M. Natalucci, and J. M. Piger [2004], "The Macroeconomic Effects of Inflation Targeting," *Federal Reserve Bank of St. Louis Review*, 86(4), 51-80.

Maruyama, T. and K. Suganuma [2020], "Inflation Expectations Curve in Japan," *Japanese Journal of Monetary and Financial Economics*, 8, 1-28.

Mehra, Y. P. [1999], "A Forward-Looking Monetary Policy Reaction Function," *Federal Reserve Bank of Richmond, Economic Quarterly*, 85(2), 33-53.

Mitchell, K. and D. K. Pearce [2010], "Do Wall Street Economists Believe in Okun's Law and the Taylor Rule?" *Journal of Economics and Finance*, 34, 196-217.

Muggeo, V. M. R. [2003], "Estimating Regression Models with Unknown Break-Points," *Statistics in Medicine*, 22(19), 3055-3071.

Muggeo, V. M. R. [2008], "Segmented: An R Package to Fit Regression Models with Broken-Line Relationships", *R News*, 8(1), 20-25.

Nakajima, J., N. Sudo, Y. Hogen, and Y. Takizuka [2023], "On the Estimation of the Natural Yield Curve," Discussion Paper Series A, 753, Institute of Economic Research, Hitotsubashi University.

Nakano, S., Y. Sugioka, and H. Yamamoto [2024], "Recent Developments in Measuring the Natural Rate of Interest," Bank of Japan Working Paper Series, No.24-E-12.

Nakazono, Y. and K. Ueda [2013], "Policy Commitment and Market Expectations: Lessons Learned from Survey Based Evidence under Japan's Quantitative Easing Policy," *Japan* *and the World Economy*, 25-26, 102-113.

Neal, R. M. [1996], *Bayesian Learning for Neural Networks*, Lecture Notes in Statistics, 118, Springer New York, NY.

Neal, R. M. [2011], "MCMC Using Hamiltonian Dynamics," In *Handbook of Markov Chain Monte Carlo*, A. Gelman, G. Jones, and X. Meng, eds., CRC Press New York, NY.

Neuenkirch, M. and P. L. Siklos [2013], "What's in a Second Opinion? Shadowing the ECB and the Bank of England," *European Journal of Political Economy*, 32, 135-148.

Nishino, K., H. Yamamoto, J. Kitahara, and T. Nagahata [2016], "Changes in the Expected Inflation Rate over Three Years of Quantitative and Qualitative Monetary Easing," Bank of Japan Review Series, 2016-J-17 (in Japanese).

Oda, N. and T. Nagahata [2005], "Monetary Policy Rules and the Conduct of Central Bank Policy," Bank of Japan Review Series, 2005-J-13 (in Japanese).

Orphanides, A. and J. C. Williams [2004], "Imperfect Knowledge, Inflation Expectations, and Monetary Policy," In *The Inflation-Targeting Debate*, B. S. Bernanke and M. Woodford, eds., University of Chicago Press, 201–246.

Pflueger, C. [2025], "Perception about Monetary Policy - 2025," Presentation at ECB Forum on Central Banking 2025, Sintra, Portugal, 2 July 2025.

Romer C. D. and D. H. Romer [2002], "A Rehabilitation of Monetary Policy in the 1950's," *American Economic Review*, 92(2), 121-127.

Sauer, S., and J. Sturm [2003], "Using Taylor Rules to Understand ECB Monetary Policy," CESifo Working Paper, 1110.

Schmeling, M., A. Schrimpf, and S. A. M. Steffensen [2022], "Monetary Policy Expectation Errors," *Journal of Financial Economics*, 146, 841–858.

Suganuma, K. and T. Yamada [2017], "Forward Rate Model with Negative Interest Rates and Market Participants' Interest Rate Outlook," IMES Discussion Paper Series, 2017-J-18 (in Japanese).

Taylor, J. B. [1993], "Discretion versus Policy Rules in Practice," *Carnegie-Rochester Conference Series on Public Policy*, 39, 195-214.

Ueno, Y. [2017], "Term Structure Models with Negative Interest Rates," IMES Discussion Paper Series, No. 2017-E-1.

Woodford, M. [2005], "Central Bank Communication and Policy Effectiveness," *Proceedings* *of 2005 Jackson Hole Economic Policy Symposium*, 399-474.

Appendix A: Perceived Policy Reaction Function and the Taylor Principle

This Appendix examines the relationship between the policy reaction function estimated in this paper and the Taylor principle. The Taylor principle refers to the required condition on the inflation coefficient in the Taylor rule for monetary policy to be effective.[25] Specifically, the required level of the inflation coefficient, denoted as $\bar{\beta}$, ensures that the nominal interest rate increases by more than the rise in inflation (i.e., the real interest rate increases as inflation rises). For the Taylor principle to hold, the condition $\beta > \bar{\beta}$ must be met.

As the Taylor principle reflects a condition tied to macroeconomic and inflation dynamics, it is considered appropriate to analyze the policy reaction function perceived by market participants based on the average of all participants. Applying the average across all market participants in equation (12) gives:

$$\begin{aligned} \mathrm{E}_t i_t^h &= \mathrm{E}_t r_{t+h}^* + \mathrm{E}_t \mathrm{TP}_t^h - (\hat{\beta}_t - \omega_t)\pi_t^* \\ &\quad + \left(1 - \omega_t + \hat{\beta}_t\right)\mathrm{E}_t \pi_{t+h} + \varepsilon_t. \end{aligned} \tag{A1}$$

where $\mathrm{E}_t i_t^h$ indicates the average nominal interest rate forecast of all market participants.

From the definition of the Taylor principle, the condition that the policy reaction function perceived by market participants satisfies the Taylor principle is equivalent to requiring that the coefficient on the average inflation expectations $\mathrm{E}_t \pi_{t+h}$ in the fourth term of equation (A1) is greater than 1. Therefore, the necessary and sufficient condition for this paper's estimated equation to satisfy the Taylor principle is $1 - \omega_t + \hat{\beta}_t > 1$, or equivalently, $\hat{\beta}_t > \omega_t$.[26]

Since ω_t is a weight that ranges from 0 to 1, the threshold for $\hat{\beta}_t$ that satisfies the Taylor principle must lie somewhere between 0 and 1. In the estimation framework of this paper, ω_t is aggregated with other common components of market participants into the time-varying constant term $\hat{\alpha}_t$, making it impossible to identify ω_t separately. As a result, within this framework, we cannot definitively determine whether $\hat{\beta}_t$ satisfies the Taylor principle when its value lies between 0 and 1.

[25] This is the basic definition of the Taylor principle as given by Taylor [1993]. More generally, it refers to the condition on model parameters in a general equilibrium model under which the long-run marginal increase in the nominal interest rate in response to inflation exceeds one, thereby ensuring the determinacy of the equilibrium. For discussions of the Taylor principle in the standard New Keynesian model, see Ascari and Sbordone [2014].

[26] In cases such as the U.S., where long-term inflation expectations are considered to be anchored to the price stability target, it is reasonable to assume that the trend inflation rate equals the price stability target, that is, $\omega_t = 1$. Under this assumption, the condition for satisfying the Taylor principle is $\hat{\beta}_t > 1$, which is consistent with the previous studies for the U. S. (Bauer et al. [2024a]).

Appendix B: Estimation Algorithm for the State-Space Model

In this Appendix, we provide an overview of the estimation algorithm for the state-space model in this paper, which is based on the Hamiltonian Monte Carlo (HMC) method.[27]

(Overview of the Hamiltonian Monte Carlo Method)

The HMC method is a technique that applies molecular dynamics, a branch of physics, to Markov Chain Monte Carlo (MCMC) methods (Duane et al., 1987; Neal, 1996).[28] Compared to other MCMC methods, this technique has a higher acceptance rate for parameter candidates and can explore the parameter space more efficiently. As a result, it is widely used for sampling from high-dimensional distributions and for estimating nonlinear models with complex posterior distributions.

In molecular dynamics, the motion of particles — the changes in coordinates and momenta — is simulated by applying equations of motion to individual molecules or atoms. On the other hand, in the HMC method, a system consisting of the parameter vector θ_τ and an auxiliary momentum vector q_τ is treated as a particle, with a virtual time τ introduced. The time evolution of this system, (θ_τ, q_τ), is considered for the virtual time τ. First, given the data Y, the Hamiltonian $\mathrm{H}(\theta_\tau, q_\tau)$ of the system (θ_τ, q_τ) is defined using the posterior distribution of the parameter vector $P(\theta_\tau|Y)$ as follows.

$$\mathrm{H}(\theta_\tau, q_\tau) = \frac{1}{2} q_\tau^\top q_\tau - \log P(\theta_\tau|Y). \tag{B1}$$

From a physical perspective, the first term on the right-hand side of equation (B1) represents the particle's kinetic energy, while the second term $-\log P(\theta_\tau|Y)$ is interpreted as the potential energy of the particle. Since the particle's potential energy decreases as the posterior probability increases, this framework encourages the selection of parameters that fit the data well during the simulation.

Under this framework, the system of the parameter vector and momentum vector (θ_τ, q_τ) evolves over the virtual time τ according to the following equations of motion.

$$\frac{d\theta_\tau}{d\tau} = \frac{\partial \mathrm{H}(\theta_\tau, q_\tau)}{\partial q_\tau}, \tag{B2}$$

[27] This estimation uses the R package *rstan*, which provides an interface for running stan within the R environment.

[28] For details of the HMC method, see Neal [2011].

$$\frac{dq_\tau}{d\tau} = -\frac{\partial \mathrm{H}(\theta_\tau, q_\tau)}{\partial \theta_\tau}. \tag{B3}$$

From equations (B1), (B2), and (B3), we have:

$$\frac{d\mathrm{H}(\theta_\tau, q_\tau)}{d\tau} = \frac{\partial \mathrm{H}(\theta_\tau, q_\tau)}{\partial \theta_\tau}\frac{d\theta_\tau}{d\tau} + \frac{\partial \mathrm{H}(\theta_\tau, q_\tau)}{\partial q_\tau}\frac{dq_\tau}{d\tau}$$

$$= 0. \tag{B4}$$

This implies that $\mathrm{H}(\theta_\tau, q_\tau)$ remains invariant over the virtual time τ.

(Estimation Algorithm for the State-Space Model)

Based on the above, we outline the estimation algorithm for the state-space model. Let the number of steps in the estimation be denoted by L and the step size by s.[29]

STEP 1: Using the prior distributions for $\hat{\alpha}_1$, $\hat{\beta}_1$, σ_ε^2, σ_1^2, and σ_2^2, as well as the state equations for $\hat{\alpha}_t$ and $\hat{\beta}_t$, create an initial value for the parameter vector $\theta^* = (\hat{\alpha}_1^*, \dots, \hat{\alpha}_T^*, \hat{\beta}_1^*, \dots, \hat{\beta}_T^*, \sigma_\varepsilon^{2*}, \sigma_1^{2*}, \sigma_2^{2*})$, where T is the final estimation period.

STEP 2: Using θ^*, the data Y, and the observation equation, estimate the posterior distribution of the parameter vector $p(\theta^*|Y)$ based on Bayes' theorem, which is derived from the likelihood calculated from the observation equation $p(Y|\theta^*)$ and the prior distribution $p(\theta^*)$:

$$p(\theta^*|Y) \propto p(Y|\theta^*)p(\theta^*).$$

STEP 3: As an auxiliary variable, randomly generate the momentum vector q_0 corresponding to the parameter vector θ^* from the standard normal distribution as follows:

$$q_0 \sim N(O, I),$$

where O is the zero vector and I is the identity matrix.

STEP 4: Set $\theta_0 = \theta^*$, and use (θ_0, q_0) as the starting point to evolve θ_τ and q_τ through the following steps. After each update of θ_τ and q_τ, calculate the Hamiltonian $\mathrm{H}(\theta_\tau, q_\tau)$ and its

[29] The number of steps L and step size s are automatically selected by the NUTS (No-U-Turn Sampler) algorithm, which is built into stan. For details of NUTS, see Hoffman and Gelman [2014].

gradient $\frac{\partial \mathrm{H}(\theta_\tau, q_\tau)}{\partial \theta_\tau}$.[30]

STEP4-1: Update the momentum vector with a half-step:

$$q_{\tau+1/2} = q_\tau - \frac{s}{2}\frac{\partial \mathrm{H}(\theta_\tau, q_\tau)}{\partial \theta_\tau}.$$

STEP 4-2: Update the parameter vector:

$$\theta_{\tau+1} = \theta_\tau + s q_{\tau+1/2}.$$

STEP 4-3: Update the momentum vector with a half-step:

$$q_{\tau+1} = q_{\tau+1/2} - \frac{s}{2}\frac{\partial \mathrm{H}(\theta_{\tau+1}, q_{\tau+1/2})}{\partial \theta_\tau}.$$

Repeat the above steps L times to obtain (θ_L, q_L).

STEP 5: Apply the Metropolis method to accept or reject θ_L. Specifically, set the acceptance rate α as:

$$\alpha = \min\left(1, \exp\left(-\mathrm{H}(\theta_L, q_L) + \mathrm{H}(\theta_0, q_0)\right)\right),$$

and accept θ_L with probability α (i.e., $\theta^* = \theta_L$) and reject with probability $1 - \alpha$ (i.e., $\theta^* = \theta_0$).[31]

STEP 6: Perform steps 2 to 5 for 500 iterations as the burn-in period, then the process 500 more times.

In this paper, the estimations are performed with four chains, using a total of 2,000 samples to plot the posterior distribution.

[30] The gradient of the Hamiltonian is automatically computed by stan using the automatic differentiation method. For details of automatic differentiation, see Baydin et al. [2018].

[31] According to equation (B4), the acceptance rate in an ideal situation is 1. This serves as the theoretical foundation for the efficiency of the HMC method in sampling. However, in practice, due to computational errors, the acceptance probability is typically less than 1.

Appendix C: Robustness Check

This paper estimates the policy reaction function perceived by market participants in Japan, using a combination of "long-term interest rates and long-term inflation expectations" as the data. In addition, to eliminate fluctuations across survey rounds and evaluate market participants' perceptions about monetary policy, the estimation employs a state-space model, assuming that the coefficients of the policy reaction function evolve constantly over time, following a random walk process.

This appendix presents robustness checks to evaluate the impact of changes in the estimation method. In particular, we examine how the estimated inflation coefficient of the policy reaction function changes when a combination of "short-term interest rates and short-term inflation expectations" is employed as the data. Furthermore, we compare the findings from a cross-sectional regression model with those obtained from the state-space model.

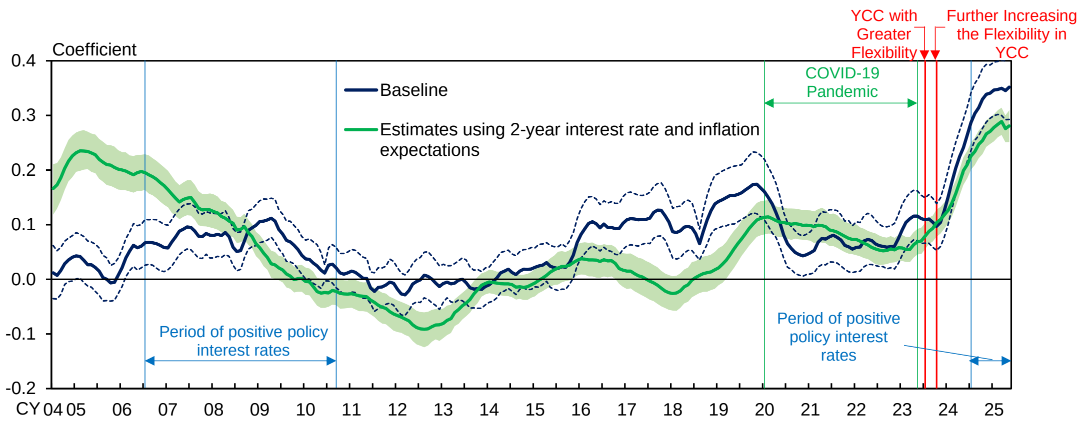
(Using Short-Term Forecast Data)

We estimate the policy reaction function perceived by Japan's market participants by using the 2-year interest rate forecasts and the 2-year inflation expectations. As explained in Section 2.2, the estimated coefficients remain unchanged regardless of whether short-term or long-term forecast data are employed, as long as the data are unbiased. However, Figure 1 shows that, despite the large-scale monetary easing, the 10-year interest rate forecast still has room for further cuts, while the 2-year interest rate forecast appears to be influenced by the effective lower bound on the nominal interest rate since the 2008 financial crisis. This aligns with prior research, which often uses long-term forecast data.

The inflation coefficient estimated from 2-year forecasts shows a sharp increase during the current rate hike phase following the "Conducting YCC with Greater Flexibility" and "Further Increasing the Flexibility in the Conduct of YCC." This increase aligns with the main analysis (Figure C1). However, when nominal interest rates were constrained by the effective lower bound, the coefficient was statistically significant but negative, complicating its interpretation.

These results indicate that the main conclusion holds even when short-term expectation data is used in place of long-term expectation data. Specifically, the findings suggest that Japan's market participants updated their perceptions about monetary policy in response to policy changes, such as the increased flexibility of YCC. However, the analysis also found that, when short-term expectation data was used, the estimated inflation coefficients were statistically significant and negative during certain periods, making interpretation challenging. Considering these findings, it is deemed more suitable to use long-term expectation data when estimating the policy reaction function perceived by private agents in Japan, where nominal short-term interest rates have long been constrained by the effective lower bound.

Figure C1. Using Short-Term Forecast Data



Source: QUICK Monthly Market Survey <Bonds>

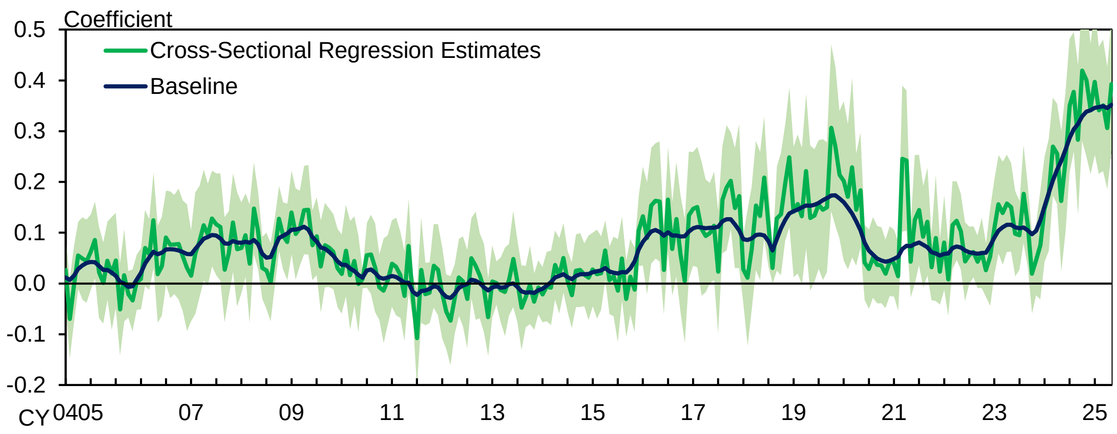
Note: The bold line represents the median, the shaded area and dashed lines indicate the 95% credible interval, and the red line marks the policy change event.

(Using a Cross-Sectional Regression Model)

In our baseline analysis, the estimation was conducted using a state-space model framework to mitigate the influence of fluctuations across survey periods. However, many previous studies have employed a cross-sectional regression framework for their analyses (Bauer et al., 2024a, 2024b, 2025; Ichiue, 2024; ECB, 2025; etc.).

Using the cross-sectional regression framework to analyze the perceived policy reaction function in equation (10), we find that the results are broadly consistent with the baseline estimates from the state-space model, despite relatively large fluctuations (Figure C2).

Figure C2. Using a Cross-Sectional Regression Model



Source: QUICK Monthly Market Survey <Bonds>

Note: The shaded area represents the 95% confidence interval from the cross-sectional regression, while the baseline is the median in Figure 3.