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【要旨】

This paper reviews the Bank of Japan's (BOJ) monetary policy from the perspective of surprise observed in the foreign exchange market and investigates the potential of central bank's surprising announcement as a policy tool to change people's deflationary mindset. We propose a surprise measure that is based on the daily candlestick-chart data on the yen-dollar exchange rate and identify surprise that occurred in the Tokyo and New York markets. Using the identified surprise, we evaluate monetary policies of BOJ governors and compare them with those of Fed chairs. We present statistical evidence that shows that under the command of Governor Haruhiko Kuroda, the BOJ was strongly dependent on surprise policy in the course of the quantitative and qualitative monetary easing. We also show that the surprise generated during the Kuroda term succeeded in raising the trend inflation rate, but failed to steepen the slope of the Phillips curve and to enhance the pass-through of the foreign exchange rate.

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Central Bank's Surprise Policy And Its Potential To Change People's Deflationary Mindset: Evidence From the Yen-Dollar Exchange Market

Koichiro Kamada*

July 14, 2025

Abstract

This paper reviews the Bank of Japan's (BOJ) monetary policy from the perspective of surprise observed in the foreign exchange market and investigates the potential of central bank's surprising announcement as a policy tool to change people's deflationary mindset. We propose a surprise measure that is based on the daily candlestick-chart data on the yen-dollar exchange rate and identify surprise that occurred in the Tokyo and New York markets. Using the identified surprise, we evaluate monetary policies of BOJ governors and compare them with those of Fed chairs. We present statistical evidence that shows that under the command of Governor Haruhiko Kuroda, the BOJ was strongly dependent on surprise policy in the course of the quantitative and qualitative monetary easing. We also show that the surprise generated during the Kuroda term succeeded in raising the trend inflation rate, but failed to steepen the slope of the Phillips curve and to enhance the pass-through of the foreign exchange rate.

Keywords: deflationary mindset, monetary policy surprise, exchange rate, candlestick chart, trend inflation

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1. Introduction

The purpose of this paper is to review the Bank of Japan's (BOJ) monetary policy from the viewpoint of surprise, with a special focus on the *quantitative and qualitative monetary easing* (QQE) conducted under the command of Governor Haruhiko Kuroda (2013-2023). To achieve its inflation rate target of 2% with its policy rate on the zero lower bound, the BOJ started the QQE, purchasing various assets, such as JGB, ETF, and J-REIT, from financial markets and providing monetary base to them. Later, to reinforce the QQE, the BOJ introduced new policy measures one after another, including *negative interest rates*, *yield curve control*, and *inflation-overshooting commitments*.

At the beginning of the QQE, due to its huge scale of asset purchase, the BOJ's policy during the Kuroda term was called *Kuroda bazooka* and received positively by the media. As time went by, however, particularly after the introduction of negative interest rates, the BOJ was criticized severely for operating *surprise policy* by the media. Today's central banks are required to keep high accountability in policy implementation in return for their independence. In fact, through their experiences, central bankers understand that abrupt and unforeseeable policy actions should be avoided since they generate confusion in financial markets without any sure returns. Surprise policy is clearly against the recent trend of monetary policy practices.

Surprise policy, however, may be justified if there is no alternative policy measure for achieving central bank's primary goal, that is, price stability in the case of the BOJ. The BOJ has never expressed its policy as surprise policy, so that we are not sure whether it conducted surprise policy intentionally and, if it did, why. Nonetheless, the circumstances surrounding the BOJ during the Kuroda term allow us to make the following conjecture: Japan's long-lasting deflation was supported by people's stubborn mindset; a strong shock therapy was required for the purpose of removing this mindset and achieving the target rate of inflation. Rajan (2023) calls it a *shock-and-awe operation*.[1]

Regarding the above discussion, we address two issues. The first is whether the

[1] Surprise policy during the Kuroda term can also be viewed as a positive application of the Lucas (1976) critique, i.e., an intentional policy change for the purpose of restructuring the stagnant economy.

BOJ's policy during the Kuroda term can be characterized as surprise policy by a formal statistical test. The criticism by the media seems to be heavily dependent on the strong impressions of a few striking events. No central bank governors, however, could complete his whole career without generating any surprise in complexly interconnected modern financial markets. A fair evaluation therefore should be based on all the policies implemented during his whole career as a central bank governor. In this paper, we conduct formal tests and present statistical evidence that indicates that the BOJ was strongly dependent on surprise policy in the course of the QQE during the Kuroda term.

The second issue we address is whether surprise policy during the Kuroda term could affect the development of inflation rates in Japan. Surprise policy gives all pain and no good to financial markets, if it fails to save the Japanese economy from the long-lasting deflation. In this paper, we conduct regression analysis to see whether surprise policy affected the structure of the Phillips curve. The result suggests the possibility that surprise policy during the Kuroda term succeeded in raising the trend inflation rate or inflation expectations, but failed to steepen the slope of the Phillips curve and to strengthen the pass-through of foreign exchange rates.

One of the novel points in this paper is the method for identifying surprise in financial data. Surprise is captured as a deviation of a realized value from its expected value in general. Recently, high-frequency data on futures markets have attracted much attention for the purpose of estimating expectations. Tick-by-tick data are particularly useful since they record individual trades with timestamps counted by seconds or sometimes by milliseconds. Tick-by-tick data, however, are extremely expensive to access and sometimes need expertise to handle. In this paper, we use daily candlestick charts, instead of tick-by-tick data, which is inexpensive and easy to handle (see Appendix A for a brief introduction of candlestick charts).

To estimate expectations, we take an approach proposed by Kamada, et al. (2022). In their theoretical model, traders attempt to predict an impact of a certain event before its occurrence. Based on their predictions, traders buy or sell assets in the market, which makes asset prices rise and fall. Thus, the volatility of asset prices observed prior to the event reflects traders' predictions. This theoretical implication enables us to infer traders' expectations and to calculate the magnitude of surprise from asset price data. We modify their original method, which is designed for tick-by-tick data, so as to use daily data.

Another novel point is that our surprise measure is based on foreign exchange rates. In a normal situation, short-maturity futures rates have many qualifications for a source data of a monetary policy surprise measure. For instance, they are strongly related to monetary policy instruments; they move freely without any restriction. Short-maturity futures rates did not move much, however, due to the liquidity trap in Japan at least until the introduction of negative interest rates. Furthermore, short-term interest rates were no longer a policy instrument of the BOJ under the QQE, so that short-maturity futures lost a strong relationship with monetary policy. In this paper, we use the foreign exchange rate, instead of short-maturity futures rates. The yen-dollar exchange rate has no restriction to move and responds much to the BOJ's policy announcements.[2]

The remainder of this paper is organized as follows. Section 2 reviews the preceding literature. Section 3 explains the theoretical model that gives a foundation for estimating market expectations and measuring surprise. Section 4 proposes an empirical method for identifying surprising events, based on daily candlestick-chart data. Section 5 presents a bird's-eye view of surprise identified in the foreign exchange market. Section 6 tests BOJ governors for surprise policy and compare them with Fed chairs. Section 7 examines the potential of surprise policy to change the structure of the Phillips curve. Section 8 concludes the paper with some remarks on further research.

2. Literature Review

Monetary policy surprises have recently attracted much attention in the academic literature since high frequency data on many markets become accessible. Particularly, tick-by-tick data, which record trade information every second or every millisecond,

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[2] Central bankers in advanced countries are extremely careful when referring to foreign exchange rate matters. The BOJ had to explain the purpose of the QQE carefully at the time of its introduction, i.e., the achievement of its target inflation rate of 2%, not the manipulation of foreign exchange rates.

have changed the way of extracting necessary shocks from noisy data. In monetary policy analysis, it is important to distinguish between expected and unexpected (or surprising) shocks and to examine which shocks have significant effects on what variables. A traditional method of identifying surprise is to conduct a survey in the associated market. However, the frequency of a survey, usually once in a month, a quarter, a year, is too low to capture surprise generated by a specific event correctly.

Several methods are proposed for the identification of surprise. The first method is to calculate surprises from VAR innovations. For instance, Christiano, et al. (1996) propose a VAR model for estimating an exogenous monetary policy shock. This shock is identified as a deviation from a monetary policy rule and assumed hard to be predicted before policy implementation. This is a versatile method of identifying surprise, based on time-series data of any frequency, and is applicable broadly to the analysis of monetary policy effects (e.g., Edelberg and Marshall, 1996).

The second method of measuring surprises is pioneered by Kuttner (2001) and uses a daily change in the Fed funds futures rate as a proxy of an unexpected or surprising change in the Fed funds target. The futures rate at the close of the market reflects all the expectations that were made during the day as well as all the facts that occurred on the day and before. If the futures rate moves on the meeting day of the Federal Open Market Committee (FOMC), it indicates that the statement includes information new to market participants and generates surprise in the market.

To purify Kuttner's measure, Gürkaynak, et al. (2005) use tick-by-tick data on the federal funds futures and propose a rate change in a narrow window around the FOMC announcement, thirty minutes or an hour, as a measure of surprise. Due to its ability of capturing noise-free surprising monetary policy shocks, their measure has become increasingly popular in monetary policy analysis (e.g., Andersson, 2010; Fleming and Piazzesi, 2005; Nakamura and Steinsson, 2018; Nakamura, 2024).

The third method of measuring surprise is the one proposed by Kamada, et al. (2022), who present a theoretical model of expectation formation and use its implication to develop a surprise measure. This method uses no surveys, no futures market data, and no large VAR models to estimate expectations and surprise, but needs tick-by-tick data to exploit their rich information regarding individual trades, such as times, prices, directions of trades. As mentioned in the introduction, tick-by-tick data are too expensive to access and need expertise to handle. Thus, analyses based on them are hard to be reproducible and to be applicable to other analysis. For this reason, we redesign Kamada, et al.'s original method for the use of daily data. More concretely, we use three data points during a day: high-, low-, and close-prices. They are known as components of a *candlestick chart* and are relatively inexpensive to access and easy to handle.

As mentioned in the introduction, the use of short-maturity futures rates may be problematic for identifying monetary policy surprises when short-term interest rates hit the zero or effective lower bound. Kubota and Shintani (2022) display the intraday tick-by-tick movements of 3-month Euroyen futures rates on April 4, 2013 and point out that no change was observed around the press release of the introduction of the QQE by the BOJ. One of natural reactions to this problem is to use long-term interest (futures) rates (e.g., Wight, 2012). However, the Japanese government bond yield, which gave a benchmark to other long-term rates, was controlled by the BOJ tightly at zero percent under its yield curve control (YCC) from 2016, whereby the futures rate was inactive and almost useless for a source data of a surprise measure.[3] In contrast, the yen-dollar exchange rate responded sensitively to the BOJ's policy introduction, as shown in Ikkatai, et al. (2024). We produce a surprise measure from the yen-dollar exchange rate data in this paper.

Most papers on the effects of monetary policy shocks focus on the effects on financial variables (e.g., Kuttner, 2010; Kubota and Shintani, 2022) and report that significant impacts are observed on long-term interest rates even when short-term interest rates hit the effective lower bound. In the meanwhile, a relatively small number of papers investigate the effects of monetary policy surprises on macroeconomic variables, such as the output and prices (e.g., Edelberg and Marshall, 1996; Nakamura, et al., 2024). However, their opinions about the effectiveness of surprise policy on macroeconomic variables are divided. Further empirical studies are required until we

[3] Stock prices moved freely in reaction to the BOJ's large-scale purchase of ETFs under the QQE and thus can be a candidate of a source data of a monetary policy surprise measure.

reach a consensus view.

To investigate the effects of monetary policy surprises on inflation rates in Japan, we examine the variability of the structure of the Phillips curve due to surprise generated by the BOJ. Using a state-space model, Kaihatus and Nakajima (2015) and Okimoto (2019) estimate the time-varying Phillips curve in Japan and suggest that the trend inflation rate rose around the introduction of the inflation target of 2% and the start of the QQE (see also Koeda, 2019). Their investigation, however, do not distinguish expected and unexpected (or surprising) monetary policy shocks. This paper examines the potential of surprise policy to change the structure of the Japanese Phillips curve.

Lastly, we make a comment on the use of candlestick-chart data in this paper. Most of the literature on candlestick-chart analysis focuses on predictive power or profitability of specific chart-patterns (e.g., Caginalp and Laurent, 1998; Lu, et al., 2012). This paper is not interested in adding a candlestick-chart-based forecasting technique to the literature. We use candlestick charts since they reflect traders' expectations of future asset prices and thereby can be used to estimate traders' expectations and surprise. We explain how candlestick-chart data are related to the key variables in the theoretical model of Kamada, et al. (2022), particularly to market surprise, in this paper.

3. The Theoretical Model

In this section, we present the theoretical model, which gives us a foundation of empirical strategy used in later sections. The structure of the model is basically the same as presented by Kamada, et al. (2022), which is designed for the analysis of long-term bond (futures) markets. We reinterpret their model in the context of investments in foreign exchange markets. Here we explain only its essence intuitively. Readers who are interested in the mathematical details of the model are recommended to consult their original paper.

3.1. The determination of the fair exchange rate

Consider the yen-dollar exchange market. Denote the price of the dollar in terms of the yen by r_τ, where τ indicates a period. There are two states in the market: the strong-dollar state denoted by H and the weak-dollar state denoted by L. We denote the corresponding exchange rates by r_H and r_L $(< r_H)$, respectively. Traders are not sure in which state they are, but have subjective probabilities over the two states: π_τ and $1 - \pi_\tau$. When public information reaches the market in period τ, the exchange rate is adjusted as[4]

$$r_\tau = \pi_\tau r_H + (1 - \pi_\tau) r_L. \tag{1}$$

We call r_τ the fair exchange rate below. Alternatively, we rewrite this as

$$r_\tau = r_L + \frac{r_H - r_L}{1 + \theta_\tau}, \tag{2}$$

where $\theta_\tau \equiv (1 - \pi_\tau)/\pi_\tau$ is the likelihood ratio of state L over H. As θ_τ increases, the likelihood of the strong-dollar state declines and the dollar depreciates. Since traders receive the same public information, θ_τ (or π_τ) is common to all of them.

Public information does not necessarily convey correct information about states. It is correct with probability q_τ (> 0.5) and wrong with probability $1 - q_\tau$. Traders update their subjective probability following Bayes' rule: $\theta_\tau = \omega_\tau \theta_{\tau-1}$, where $\omega_\tau = (1 - q_\tau)/q_\tau$ when new public information suggests state H; $\omega_\tau = q_\tau/(1 - q_\tau)$ when it suggests state L. Due to this defect of public information, traders remain unsure about states. Note that ω_τ (or q_τ) is common to all market participants.[5] Equation (2) is written alternatively as

$$r_\tau = r_L + \frac{r_H - r_L}{1 + \omega_\tau \theta_{\tau-1}}. \tag{3}$$

3.2. *Expected exchange rates and the definition of surprise*

There are two types of traders in the market: market makers and speculators. Market makers take orders from speculators and adjust the exchange rate along their upward-sloping demand-supply schedule. As speculators' buy-orders increase, market makers

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[4] There are two types of information, public and private. Every trader has a free access to public information, while only limited traders are allowed to access private information.

[5] All traders see the same exchange rate, r_τ; there is a one-to-one correspondence between r_τ and θ_τ; thus, θ_τ is common among all traders, and so are ω_τ and q_τ.

raise the price of the dollar against the yen above the fair exchange rate; as speculators' sell-orders increases, they lower the price of the dollar against the yen below the fair exchange rate.

Speculators are divided into two types: type-ℓ speculators have a dollar-long-and-yen-short position; type-s speculators have a dollar-short-and-yen-long position. Before betting, speculators collect private information to predict a future change in the exchange rate. Denote his private information by $x_{i\tau}$; they also take into consideration the exchange rate offered in the market, i.e., $r_{o\tau}$ for $o \in \{\ell, s\}$. By definition, speculators' expected likelihood ratio of state L over H is given as

$$\hat{\theta}_{oi\tau} = \frac{\Pr\,(L|x_{i\tau}, r_{o\tau})}{\Pr\,(H|x_{i\tau}, r_{o\tau})}. \tag{4}$$

Using Bayes' rule, we rewrite this as

$$\hat{\theta}_{oi\tau} = \hat{\omega}_{oi\tau}\theta_{\tau-1}, \tag{5}$$

where

$$\hat{\omega}_{oi\tau} = \frac{\Pr(x_{i\tau}, r_{o\tau}|L)}{\Pr(x_{i\tau}, r_{o\tau}|H)}. \tag{6}$$

With the expected likelihood ratio above, speculators predict the exchange rate as

$$\hat{r}_{oi\tau} = r_L + \frac{r_H - r_L}{1 + \hat{\theta}_{oi\tau}} = r_L + \frac{r_H - r_L}{1 + \hat{\omega}_{oi\tau}\theta_{\tau-1}}. \tag{7}$$

Consider speculator i of type-ℓ. As $\hat{\omega}_{\ell i\tau}$ declines, $\hat{\theta}_{\ell i\tau}$ also declines, and $\hat{r}_{\ell i\tau}$ rises. Suppose that he obtains extremely good private information suggesting state H, or that the price of the dollar offered by market makers is extremely high, which informs him that many speculators obtain private information suggesting state H. In either case, he is almost sure that private information is released from state H. However, $\hat{r}_{\ell i\tau}$ does not reach r_H, since $\hat{\omega}_{\ell i\tau}$ does not reach zero due to the defects of public information. He is not sure whether it is released correctly from state H with expected subjective probability $\hat{q}_{\ell\tau}$ or wrongly from state L with expected subjective probability $1 - \hat{q}_{\ell\tau}$. Therefore, the floor of $\hat{\omega}_{\ell i\tau}$ is given by $\underline{\omega}_{\ell\tau} = (1 - \hat{q}_{\ell\tau})/\hat{q}_{\ell\tau}$, and thus the ceiling of $\hat{r}_{\ell i\tau}$ is given by

$$\bar{r}_{\ell\tau} = r_L + \frac{r_H - r_L}{1 + \underline{\omega}_{\ell\tau}\theta_{\tau-1}}. \tag{8}$$

We assume that $\underline{\omega}_{\ell\tau}$ or $\hat{q}_{\ell\tau}$ is common to all type-ℓ speculators for simplicity.

A similar argument can be made for the expectation formation of speculator i of type-s. As $\hat{\omega}_{si\tau}$ rises, $\hat{\theta}_{si\tau}$ rises, and $\hat{r}_{si\tau}$ declines. Suppose that she obtains extremely good private information suggesting state L, or that the price of the dollar offered by market makers is extremely low, which informs her that many speculators obtain private information suggesting state L. In either case, she is almost sure that private information is released from state L. However, $\hat{r}_{si\tau}$ does not reach r_L, since $\hat{\omega}_{si\tau}$ does not become infinitely high due to the defects of public information. She is not sure whether it is released correctly from state L with expected subjective probability $\hat{q}_{s\tau}$ or wrongly from state H with expected subjective probability $1 - \hat{q}_{s\tau}$. Therefore, the ceiling of $\hat{\omega}_{si\tau}$ is given by $\bar{\omega}_{s\tau} = \hat{q}_{s\tau}/(1 - \hat{q}_{s\tau})$, and thus the floor of $\hat{r}_{si\tau}$ is given by

$$\underline{r}_{s\tau} = r_L + \frac{r_H - r_L}{1 + \bar{\omega}_{s\tau}\theta_{\tau-1}}. \tag{9}$$

We assume that $\bar{\omega}_{s\tau}$ or $\hat{q}_{s\tau}$ is common to all type-s speculators for simplicity.

To summarize the above argument, we have[6]

$$\underline{r}_{s\tau} \leq \hat{r}_{si\tau} \leq r_{\tau-1} \leq \hat{r}_{\ell i\tau} \leq \bar{r}_{\ell\tau}. \tag{10}$$

Suppose a situation that r_τ falls between $\underline{r}_{s\tau}$ and $\bar{r}_{\ell\tau}$ when public information is released. Then we say that the situation is within expectations of speculators. Suppose another situation that r_τ takes on a value above $\bar{r}_{\ell\tau}$ or below $\underline{r}_{s\tau}$. Then we say that the situation is out of expectations of speculators. This provides the definition and the measure of surprise in this paper: surprise occurs if $r_\tau < \underline{r}_{s\tau}$ or $\bar{r}_{\ell\tau} < r_\tau$ and is measured by $\ln \underline{r}_{s\tau} - \ln r_\tau$ or $\ln r_\tau - \ln \bar{r}_{\ell\tau}$, respectively. Inequalities (10) are equivalent to the following relationship.

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[6] Fama (1970) concludes that the efficient market hypothesis in the strong form is not valid in a strict sense, i.e., not all private information is shared among all traders in the market. This implies that traders' expected exchange rates spread over the domain defined in equation (10), but do not converge.

$$\underline{\omega}_{\ell\tau} \leq \widehat{\omega}_{\ell i\tau} \leq 1 \leq \widehat{\omega}_{si\tau} \leq \overline{\omega}_{s\tau}. \tag{11}$$

Thus, we can say that surprise occurs if $\omega_\tau < \underline{\omega}_{\ell\tau}$ or $\overline{\omega}_{b\tau} < \omega_\tau$ and is measured by $\ln \underline{\omega}_{\ell\tau} - \ln \omega_\tau$ or $\ln \omega_\tau - \ln \overline{\omega}_{s\tau}$, respectively. This measure is convenient for time aggregation of surprise and thus used intensively in the empirical analysis below.[7]

3.3. Some implications for empirical analysis

We have two important comments on the relationship between $\hat{r}_{oi\tau}$ and $r_{o\tau}$ for $o \in \{\ell, s\}$. First, we have inequalities for $r_{o\tau}$ similar to inequalities (10). Speculators have different expectations from one another due to private information. Suppose that we have $\hat{r}_{\ell i\tau} > r_{\ell\tau}$ for all type-ℓ speculators. Then they are all inclined to buy dollars. Market makers raise the exchange rate $r_{\ell\tau}$ in response. Suppose alternatively that we have $\hat{r}_{\ell i\tau} < r_{\ell\tau}$ for all type-ℓ speculators. Then no one buys dollars. Market makers lower the exchange rate $r_{\ell\tau}$ in response. Consequently, we see $\hat{r}_{\ell i\tau} > r_{\ell\tau}$ for some i and $\hat{r}_{\ell i\tau} < r_{\ell\tau}$ for the others, i.e., $\hat{r}_{\ell i\tau}$'s scatter around $r_{\ell\tau}$ in equilibrium. A similar argument holds for type-s speculators, i.e., $\hat{r}_{si\tau}$'s scatter around $r_{s\tau}$ in equilibrium. This implies that $r_{\ell\tau}$ and $r_{s\tau}$ share the same domain with $\hat{r}_{\ell i\tau}$ and $\hat{r}_{si\tau}$, respectively. That is,

$$\underline{r}_{s\tau} \leq r_{s\tau} \leq r_{\tau-1} \leq r_{\ell\tau} \leq \bar{r}_{\ell\tau}. \tag{12}$$

Second, it is not very rare for us to observe $r_{\ell\tau}$ near $\bar{r}_{\ell\tau}$ and $r_{s\tau}$ near $\underline{r}_{s\tau}$ in a time interval of sufficient length. As discussed by Kamada, et al. (2022), the model displays herding behavior among speculators. Equations (7) and (6) show that speculators' expectations, $\hat{r}_{oi\tau}$, depend on $r_{o\tau}$ for $o \in \{\ell, s\}$. Consider type-ℓ speculators. A rise in $r_{\ell\tau}$ allows them to guess an increase in the number of speculators

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[7] As $\hat{q}_{\ell\tau}$ and $\hat{q}_{s\tau}$ increase to 1, the domain of expectations $[\underline{r}_{s\tau}, \bar{r}_{\ell\tau}]$ expands to $[r_L, r_H]$ ($[\underline{\omega}_{\ell\tau}, \overline{\omega}_{s\tau}]$ to $[0, \infty]$). To the contrary, as $\hat{q}_{\ell\tau}$ and $\hat{q}_{s\tau}$ decrease to 0.5, the domain of expectations degenerates to the point of $r_{\tau-1}$ ($[\underline{\omega}_{\ell\tau}, \overline{\omega}_{s\tau}]$ to the point of 1). In words, surprise is likely to occur, when the defects of private information are large. This is suggestive for policymakers: Predictable market operations (q_τ near 1) allow policy makers to avoid surprise, while ambiguous operations (q_τ near 0.5) are likely to generate surprise.

who get private information suggesting state H and to raise their expectations, $\hat{r}_{\ell i\tau}$. This creates extra demands for the dollar and raises $r_{\ell\tau}$ further. Similarly, a decline in $r_{s\tau}$ generates a further decline in $r_{s\tau}$. Consequently, the distribution of $r_{o\tau}$ becomes fat-tailed, and thus $r_{o\tau}$ takes extreme values frequently.

4. The Empirical Method

In this section, based on the implications obtained in the previous section, we propose the procedure for identifying and measuring surprise from the daily candlestick-chart data on the yen-dollar exchange rate.

4.1. Identifying and measuring surprise

Surprise occurs with the release of public information but do not without it. Thus, the first step to identify surprise is to find the timing of the release of public information. For this purpose, we introduce two concepts of time: calendar-based time and information-based time. In Figure 1, the vertical axis measures the yen-dollar exchange

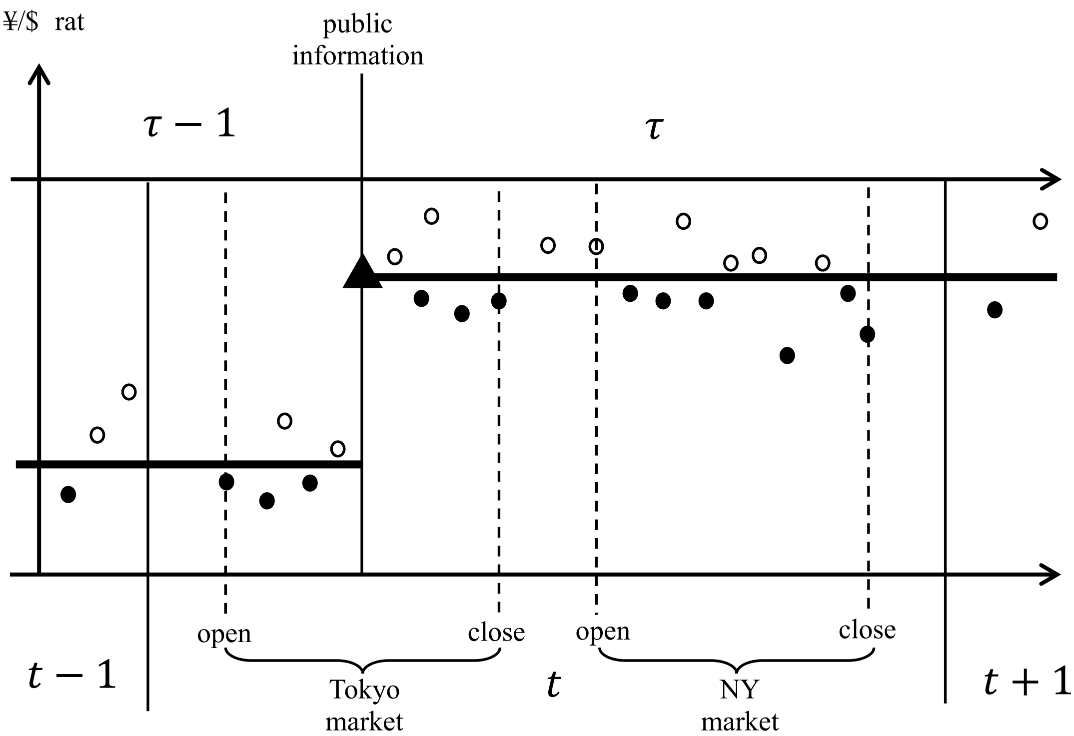

Fig. 1. Responses of tick-by-tick data to public information. Note: ▲, ○, and ● indicate $r_{\cdot}$, $r_{\ell\cdot}$, and $r_{s\cdot}$, respectively.

rates observed in markets. The horizontal axis on the bottom indicates calendar-based time. During calendar-based day t, the Tokyo market opens first as one of the major markets, followed by the Singapore, London, EU markets, and lastly by the New York market. The horizontal axis on the top indicates information-based time. The figure depicts the situation where the τ-th public information is released in the Tokyo market. Information-based period τ starts with the release of the τ-th public information and lasts until the release of the $(\tau + 1)$-th public information.

Before proposing the empirical procedure based on daily candlestick charts, we illustrate the empirical procedure based on tick-by-tick data, which are proposed by Kamada, et al. (2022). In Figure 1, it is assumed that we have the tick-by-tick data on contracted rates. As explained in the previous section, immediately after the release of the τ-th public information, the exchange rate adjusts from $r_{\tau-1}$ to r_τ. In the figure, the adjustment is illustrated by the two horizontal thick lines: the lower line for $r_{\tau-1}$ and the higher line with the black triangle for r_τ. As shown in inequalities (12), $r_{\ell\tau}$'s cluster above $r_{\tau-1}$, while $r_{s\tau}$'s cluster below $r_{\tau-1}$. This implies that if $r_{\ell\tau}$'s cluster below $r_{\tau-1}$ or $r_{s\tau}$'s cluster above $r_{\tau-1}$, it is a signal that new public information has arrived.

In this paper, however, we have only candlestick-chart data in a daily basis, instead of tick-by-tick data. Basically, we employ the same identification procedure as above, but need some adjustment. With candlestick-chart data in hand, Figure 1 is simplified to Figure 2, where two candlestick charts are presented on day t: one for the Tokyo market and the other for the New York market. Notice that the candlestick chart of the Tokyo market spans over $r_{\tau-1}$ as well as r_τ, i.e., it includes data points before as well as after the arrival of new public information. Thus, the candlestick chart of the Tokyo market does not allow us to judge whether new public information has been released. In contrast, the candlestick chart of the New York market spans over r_τ, but not over $r_{\tau-1}$, i.e., it includes only the data points after public information arrives. Therefore, the candlestick chart of the New York market can inform us of the arrival of new public information. To sum, the arrival of public information cannot be identified until a candlestick chart is obtained in the next market.

Once the timing of arrival of public information is identified, we can estimate

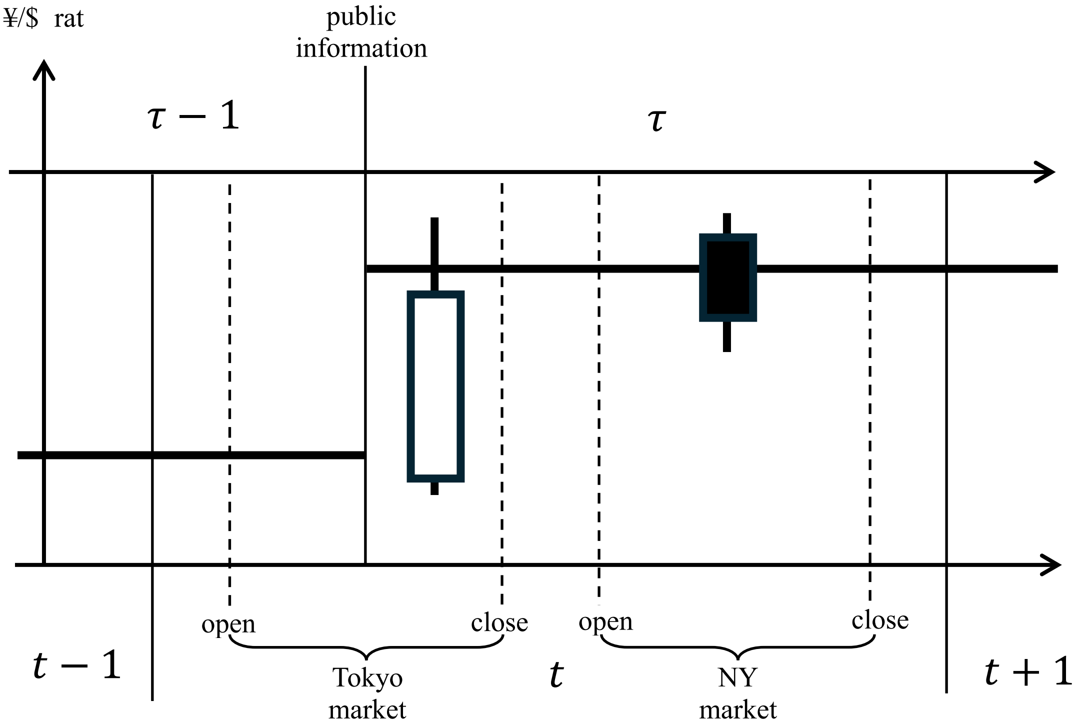

Fig. 2. Responses of daily candlestick charts to public information.

r_τ, $\bar{r}_{\ell\tau}$, and $\underline{r}_{s\tau}$ in a following way. We approximate $\bar{r}_{\ell\tau}$ by the highest among all the high-prices observed during period τ. Note that we must exclude the high-price recorded in the market where public information is released, since we are unsure that it recorded after the release of public information. Similarly, we approximate $\underline{r}_{s\tau}$ by the lowest among all the low-prices. Note that this approximation works only if period τ lasts a sufficiently long time. Lastly, we approximate r_τ by the close-price, since we are sure that it is recorded after the release of public information.

Taking the above argument into consideration, we propose the following estimation procedure of surprise.[8]

Step 1 (identification of r_τ): If the low-price of the dollar is higher than $r_{\tau-1}(1+\rho)$ or if the high-price of the dollar is lower than $r_{\tau-1}/(1+\rho)$, we infer that public information is released in the previous market and the estimate of r_τ is given

[8] Open-prices are not necessary for identifying and measuring surprise, but provide us with useful information about the exchange-rate movements inside and outside of the Tokyo and New York markets, as shown in Appendix B.

by the close-price of the dollar recoded in the previous market.

Step 2 (identification of $\bar{r}_{\ell\tau}$ and $\underline{r}_{s\tau}$): the estimate of $\bar{r}_{\ell\tau}$ is given by the highest among all the high-prices of the dollar recorded during period τ except the market where public information is released. The estimate of $\underline{r}_{s\tau}$ is given by the lowest among all the low-prices of the dollar recorded during period τ except the market where public information is released.

Step 3 (measurement of surprise): A surprising appreciation of the dollar against the yen occurs if $\bar{r}_{\ell\tau} < r_\tau$ and the surprise is measured by $\ln r_\tau - \ln \bar{r}_{\ell\tau}$. A surprising depreciation of the dollar against the yen occurs if $r_\tau < \underline{r}_{s\tau}$ and the surprise is measured by $\ln \underline{r}_{s\tau} - \ln r_\tau$.

There are two things to note in the estimation procedure above. First, in Step 1, we put a wedge of ρ (≥ 0) between a candlestick chart and $r_{\tau-1}$ to identify public information's arrival. The purpose is to avoid misidentification of the release of public information. Consider the null hypothesis that new public information is released. If ρ is too small, we commit type II error frequently. That is, although no public information arrives, we misjudge that new public information has been released. To the contrary, if ρ is too large, we commit type I error frequently. That is, although new public information has arrived, we misjudge that no public information is released. In fact, as shown in the next section, as ρ is enlarged, the number of identified arrivals of public information decreases. We keep in mind the trade-off of the two types of errors in the determination of ρ.

Second, in Step 2, surprise is measured as a percentage difference between realized and expected exchange rates, which Kamada, et al. (2022) call a price-based measure of surprise. At the same time, they propose another measure of surprise, which is called an information-value-based one.

$$\begin{array}{ll} \ln \underline{\omega}_{\ell\tau} - \ln \omega_\tau & \text{for surprising appreciation of the dollar} \\ & \text{(for surprising depreciation of the yen);} \\ \ln \omega_\tau - \ln \overline{\omega}_{s\tau} & \text{for surprising depreciation of the dollar} \\ & \text{(for surprising appreciation of the yen).} \end{array} \tag{13}$$

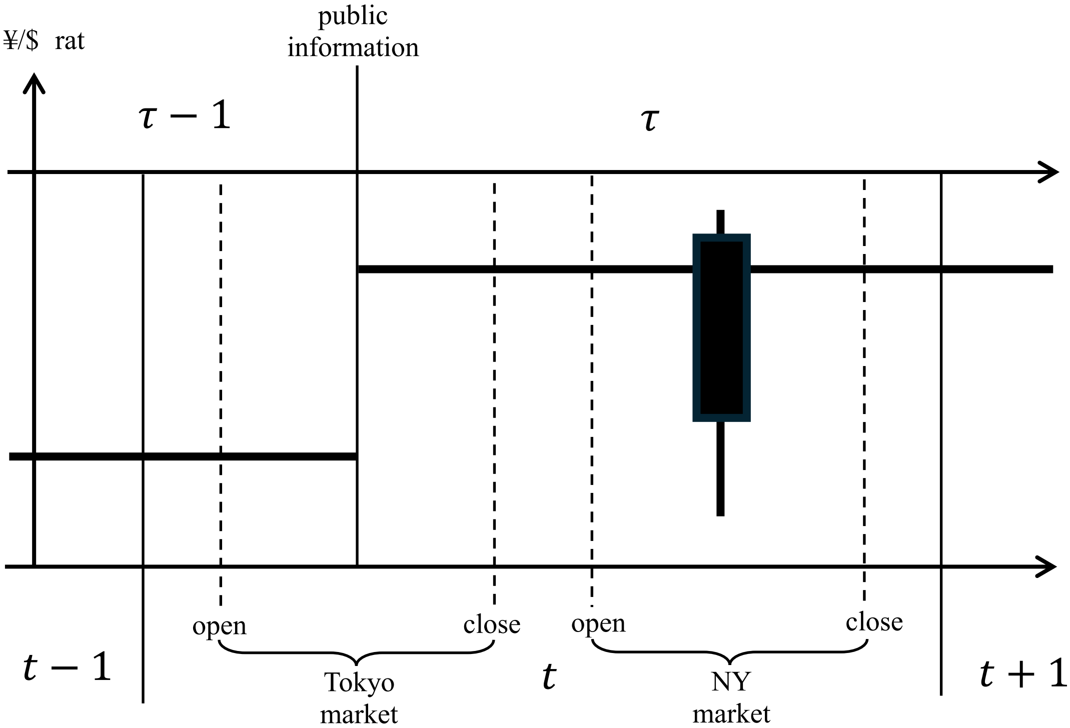

Fig. 3. Misidentification due to a large volatility of the yen-dollar exchange.

We use this measure frequently in the empirical analysis below.

4.2. Shortcomings of the estimation procedure of surprise

The above estimation procedure of surprise suffers shortcomings due to the limitation of data. Below, we present some typical cases in which the estimation procedure gives a wrong signal of public information arrival, but do not aim to present a complete list of potential errors. [9]

Case (i): As in Figure 3, the procedure fails to notice the release of state-H public information in the Tokyo market, if the exchange-rate volatility is so large due to private information that the lower wick of the candlestick chart of the New York market reaches $r_{\tau-1}$ (type I error).

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[9] It is theoretically possible to make a long list of errors to be encountered in empirical studies, but it is impractical to use such a long list when we deal with big data. To assure public information's arrival, we should make a case-by-case judgement, based on additional supporting evidence.

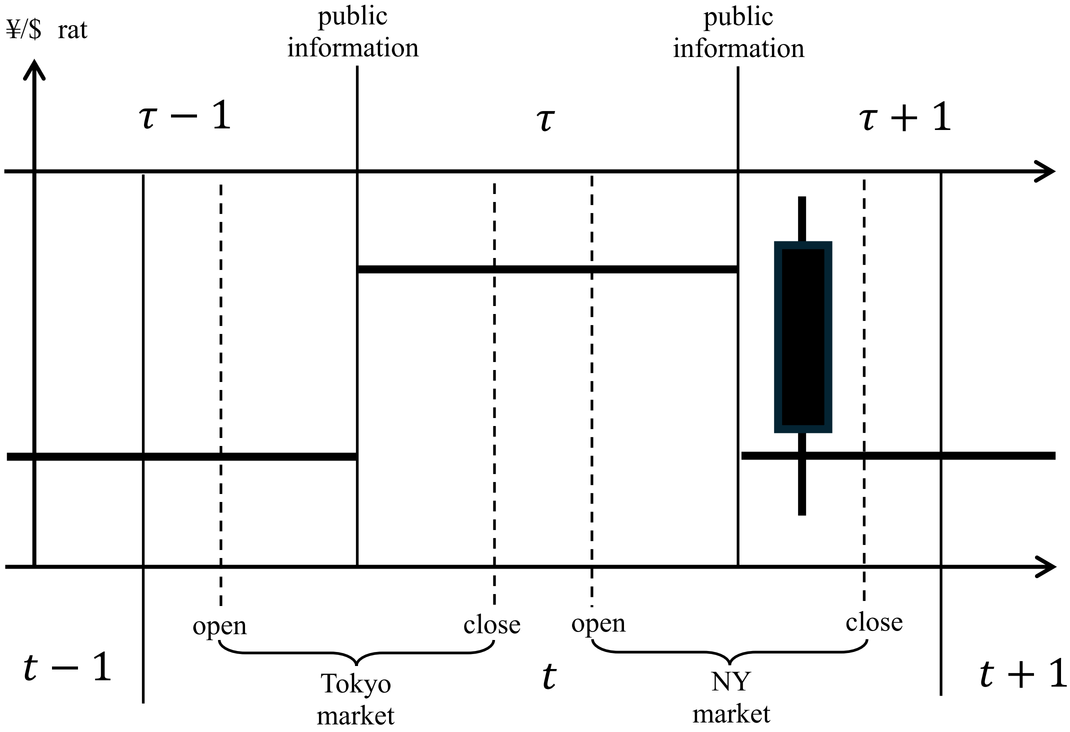

Fig. 4. Misidentification due to opposite public information release in the next market.

Case (ii): As in Figure 4, the procedure fails to notice the release of state-H public information in the Tokyo market, if state-L public information is released in the New York market (type I error).

Case (iii): As in Figure 5, the procedure conveys the wrong information that state-H public information is released in the Tokyo market, although it is really released in the London market (type II error). This is caused by the time gap between the Tokyo and New York markets of five hours (or four hours in daylight saving time).[10] As discussed in Appendix B, the yen-dollar exchange rate fluctuates largely during the time interval between the close of the Tokyo market and the open of the New York market. We should keep in mind possible effects of this misidentification.

[10] Foreign exchange markets have no official market trading hours. Conventionally, however, we understand that the Tokyo market opens at 9:00 and closes at 17:00; the New York market opens at 8:00 and closes at 17:00.

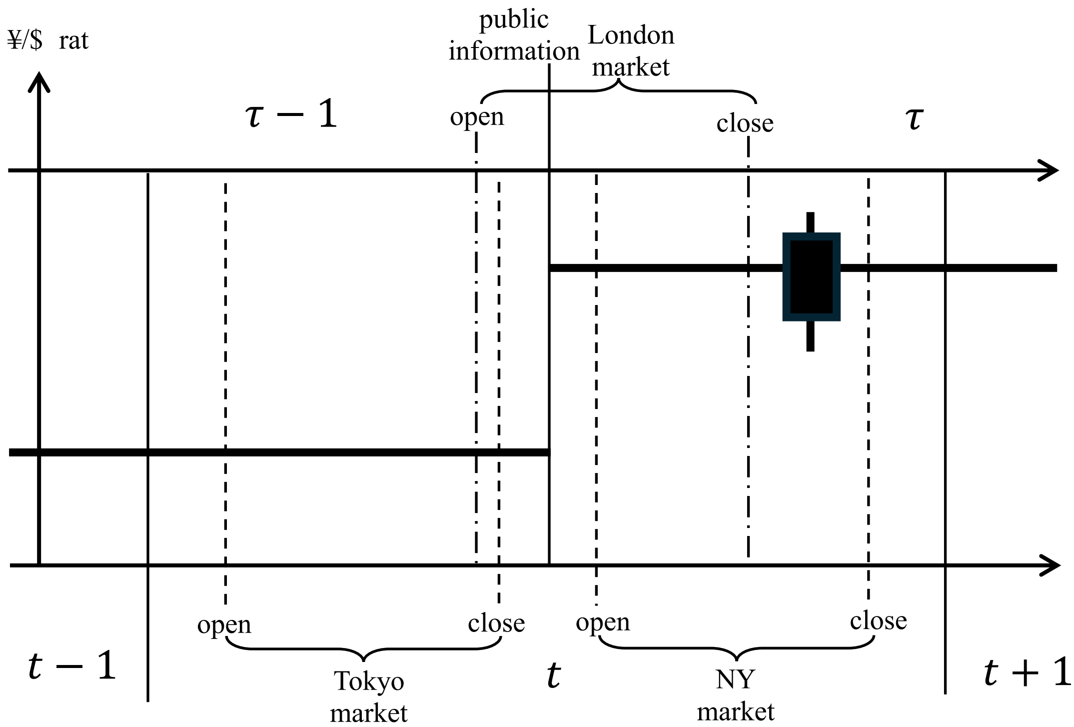

Fig. 5. Misidentification due to public information release between the two markets.

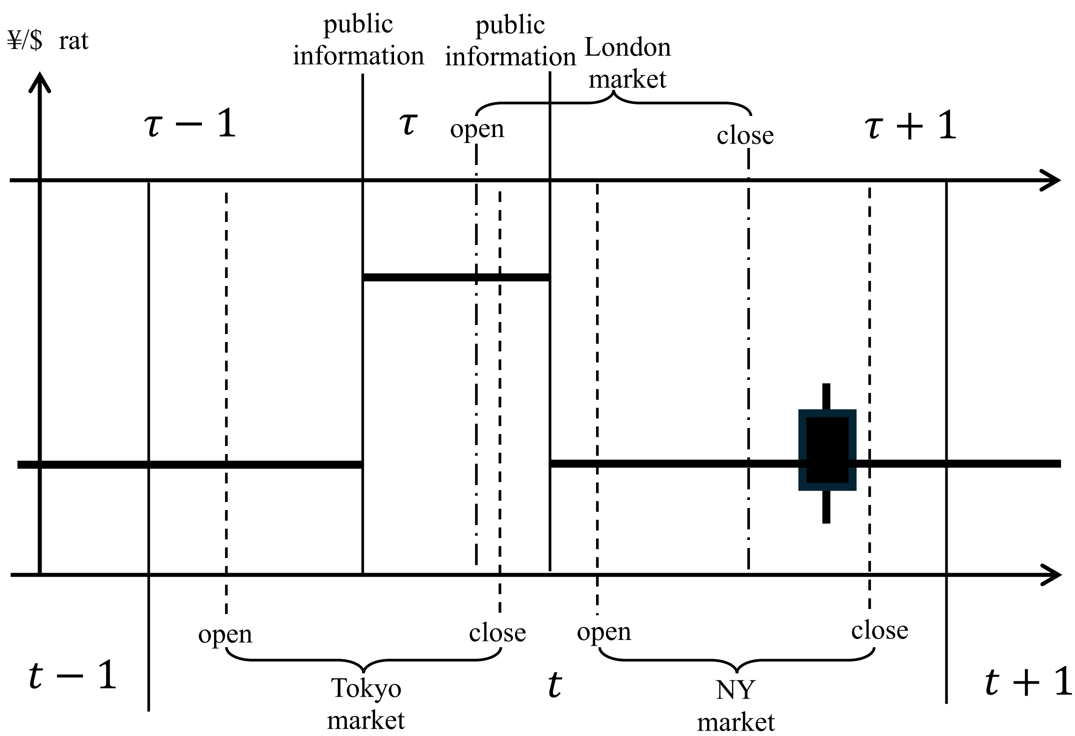

Fig. 6. Misidentification due to opposite public information release between the two markets.

Case (iv): As in Figure 6, the procedure fails to notice the release of state-H public information in the Tokyo market, if state-L public information is released in the London market (type I error).

5. A Bird's-Eye View of Identified Surprise

In this section, we identify and measure surprises by applying the empirical procedure introduced in the previous section to the daily candlestick-chart data on the yen-dollar exchange rate recorded in the Tokyo and New York markets. We investigate the identified surprise from the perspective of frequency and magnitude and find differences between the two markets by analyzing their surprise-generating process.

5.1. The data

The daily candlestick-chart data on the yen-dollar exchange rate are available in the Nikkei NEEDS. To employ the estimation procedure presented in the previous section, we need high-, low-, and close-prices. The Nikkei NEEDS has accumulated those data since January 4, 1979 for the Tokyo market and since June 5, 1984 for the New York market. Our estimation procedure works even with the data of one market. Thus, if necessary, we could conduct empirical study with the data from January 4, 1979 only with Tokyo data. By doing so, however, we would commit plenty of misidentification as discussed in the previous section. To minimize misidentification, we use the data spanning over the period of June 5, 1984 through May 15, 2024, so that our empirical study is based on both the Tokyo and the New York markets. We do not use the data of other major financial markets, such as Singapore, London, and EU markets, since the Nikkei NEEDS has no candlestick-chart data for these markets. Consequently, our sample includes 9,808 days for the Tokyo market and 9,935 days for the New York market in the following empirical study.

5.2. The frequency of surprise

To begin the estimation, we have to set the value of wedge ρ, which is a minimum deviation rate between a candlestick chart and $r_{\tau-1}$ required for the arrival of public information to be signaled. Choosing a large value of ρ means picking up only serious

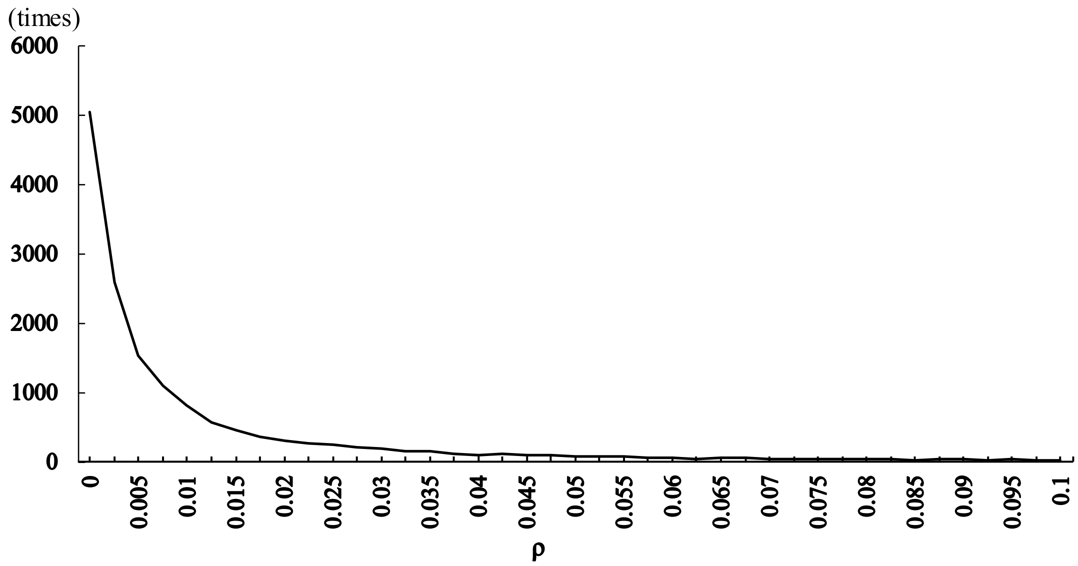

Fig 7. Number of public information events with various values of ρ

news events. Thus, as ρ increases, the number of identified public information events decreases. Figure 7 indicates the number of public information events identified with various values of ρ in the Tokyo market (we see a similar graph for the New York market). The declining speed is fast at first, but begins to slow beyond some critical value. Kamada, et al. (2022) choose such a critical value as a benchmark value of ρ. Following their method, we choose 1.0% as a benchmark value of ρ.

With ρ = 1.0%, we encounter 807 public information events in Tokyo and 772 in New York. We define the occurrence rate of public information events as follows.

$$R_m^{P/D} \equiv \frac{\#\ of\ public\ information\ events}{\#\ of\ days\ in\ the\ sample}, \tag{14}$$

where subscript m indicates a market: T for the Tokyo market and N for the New York market. Based on the estimation results, we have $R_T^{P/D}$= 8.2% and $R_N^{P/D}$= 7.8%, as shown in Table 1. Roughly speaking, we receive public information every ten business days or every two weeks in each market.

With the same value of ρ, we encounter 435 surprising news events in Tokyo and 512 in New York. Note that we do not distinguish depreciation surprise and appreciation surprise below unless otherwise indicated. Define the occurrence rate of

Table 1
Frequency of surprise

	Tokyo	New York	z-test	
# of days in the sample (D)	9,808	9,935		
# of public information events (P)	807	772		
# of surprising news events (S)	435	512		
$R^{P/D}$	8.2%	7.8%	1.2	
$R^{S/D}$	4.4%	5.2%	-2.4	**
$R^{S/P}$	53.9%	66.3%	-5.0	***

Notes: ρ = 1%. ***, **, and * indicate 1%, 5%, and 10% significance, respectively.

surprising news events as follows.

$$R_m^{S/D} \equiv \frac{\#\ of\ surprising\ news\ events}{\#\ of\ days\ in\ the\ sample}. \tag{15}$$

We have $R_T^{S/D}$= 4.4% and $R_N^{S/D}$= 5.2%, as in Table 1. To see the significance of the difference between the two markets, we conduct the two-sided proportion z-test. As shown in Table 1, we reject the null hypothesis that the two rates are equal to each other at the 5% significance level. That is, surprising news comes from New York more frequently than from Tokyo.

We also define the surprising news ratio as follows.

$$R_m^{S/P} \equiv \frac{\#\ of\ surprising\ news\ events}{\#\ of\ public\ information\ events}. \tag{16}$$

Based on the estimation results, we have $R_T^{S/P}$= 56.4% and $R_N^{S/P}$= 69.2%, as in Table 1. That is, more than half of public information generates surprise in the two markets. Furthermore, as seen in Table 1, the two-sided proportion z-test indicates that the two ratios are different from each other at the 1% significance level. That is, surprising news ratio is larger in New York than in Tokyo. This ratio is one of the key variables to evaluating each governor's monetary policy.

Lastly, we examine the time-variation of $R_T^{S/D}$ and $R_N^{S/D}$. We calculate the occurrence rate year by year for each market. The results are shown in Figure 8. The occurrence rate of surprising news events in Tokyo spikes in 1997 and 1998 due to Japan's Financial System Instability and the Asian Currency Crisis, but has no clear tendency to increase nor to decrease over the sample. In contrast, the occurrence rate in New York appears to be declining over the sample. To capture the downward trend

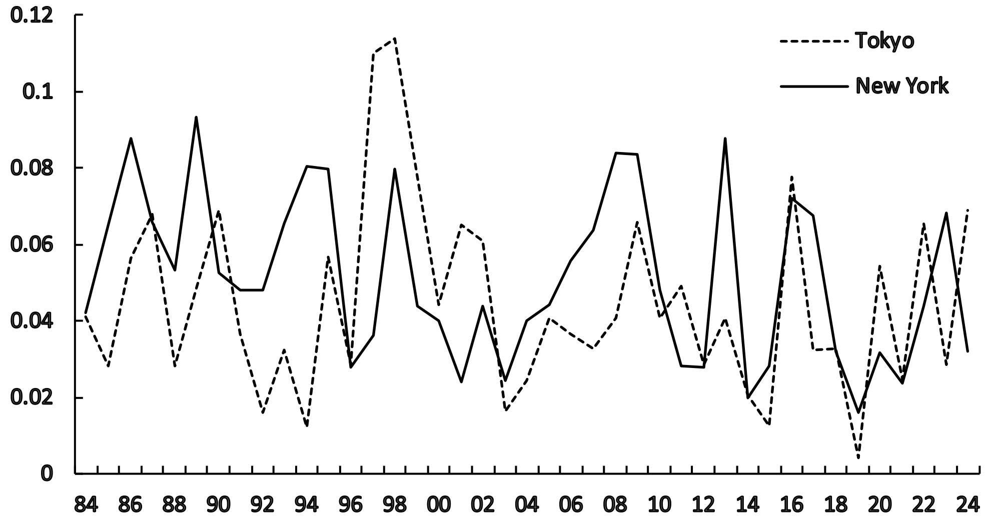

Fig 8. Occurrence rate of surprise

Table 2

Estimated trend slope of surprise frequency and magnitude

	Tokyo			New York		
	Slope	Std error		Slope	Std error	
$R^{P/D}$	-0.085	(0.052)		-0.116	(0.038)	***
$R^{S/D}$	-0.025	(0.032)		-0.062	(0.028)	**
$R^{S/P}$	0.003	(0.002)	*	0.000	(0.002)	
$R^{M/D} \times 10{,}000$	-0.075	(0.094)		-0.335	(0.130)	**
$R^{M/S} \times 10{,}000$	-1.823	(1.586)		-3.626	(1.339)	**

Notes: ρ = 1%. ***, **, and * indicate 1%, 5%, and 10% significance, respectively.

statistically, we regress the occurrence rate on a constant and a time index (= 0, 1, 2, …). The result is shown in Table 2. The estimated coefficient of the time index is negative and significant at the 5% level with $R_N^{S/D}$ as a dependent variable, while it is negative but insignificant with $R_T^{S/D}$ as a dependent variable. Similarly, we regress $R_m^{P/D}$ and $R_m^{S/P}$ on a constant and a time index. As shown in Table 2, $R_N^{P/D}$ has a downward trend at the 1% significance level; $R_T^{S/P}$ has an upward trend at the 10% significance level.

5.3. The magnitude of surprise

The estimation procedure also provides us with the magnitude of surprise. We use the information-value-based measure for this purpose. Define the per-day magnitude of surprise as follows.

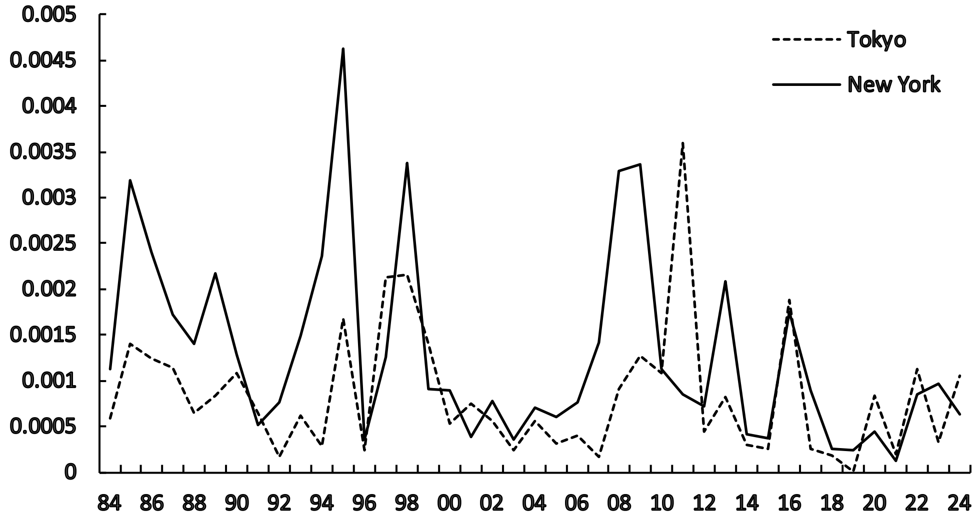

Fig 9. Per-day magnitude of surprise

$$R_m^{M/D} \equiv \frac{\Sigma|surprise|}{\#\ of\ days\ in\ the\ sample}, \tag{17}$$

where we do not distinguish depreciation surprise and appreciation surprise. Figure 9 shows the development of $R_T^{M/D}$ year by year, which was spiked in 2011 due to the Great East Japan Earthquake as well as in 1997 and 1998, but appeared stable as a whole. In contrast, $R_N^{M/D}$ follows a downward trend over the sample and has recently reached almost the same level as $R_T^{M/D}$.

For further analysis, we define the impact of surprise as follows.

$$R_m^{M/S} \equiv \frac{\Sigma|surprise|}{\#\ of surprisng\ news\ events}. \tag{18}$$

Regarding the Tokyo market, Table 2 shows that there is no significant trend slope in the development of $R_T^{M/S}$ year by year. In contrast, regarding the New York market, $R_N^{M/S}$ appears to have a downward trend; its slope is significantly negative at the 5% level. Given $R_m^{M/D} = R_m^{M/S} \times R_m^{S/D}$, the magnitude of surprise in New York tends to decrease both in frequency and in impact.

5.4. Monetary policy announcements as surprising news events

As seen in newspapers and business journals, there are many news events that affect the developments of foreign exchange rates. Some are predictable and thus unsurprising,

Table 3
Top 30 surprising events

	Tokyo			New York		
	Date	Surprise	MPM	Date	Surprise	FOMC
1	2011/8/4	-0.2864	○	1985/9/23	0.2988	○
2	2011/3/18	-0.1712		1998/10/7	0.1716	
3	2011/10/31	-0.1497		2008/10/28	-0.1440	
4	2010/9/15	-0.1372		2009/12/4	-0.1306	
5	2020/3/9	0.1048		1994/2/14	0.1224	
6	1985/9/30	0.0987		1993/8/19	-0.1176	
7	2011/1/6	-0.0884		1998/6/17	0.1139	
8	1985/9/24	-0.0882		1995/3/7	0.1126	
9	1999/2/16	-0.0787		1995/5/11	-0.1098	
10	1995/4/10	0.0758		1995/5/26	0.1087	
11	1985/9/26	0.0722		1995/3/31	0.1050	
12	1997/5/20	0.0666		1997/8/8	0.1032	
13	2008/3/17	0.0666		1995/8/15	-0.0981	
14	1999/1/12	-0.0656		1995/5/25	0.0967	
15	2016/4/28	0.0650	○	2011/3/16	0.0966	
16	1993/6/25	0.0611		1988/1/15	-0.0952	
17	1989/9/25	0.0608		1984/10/23	0.0879	
18	1986/2/21	-0.0602		1995/4/20	-0.0866	
19	1998/4/10	0.0584		2013/6/11	0.0849	
20	1998/9/11	0.0577		2022/11/10	0.0843	
21	1997/6/9	0.0571		2009/3/18	0.0836	○
22	1995/4/17	0.0557		2008/3/18	-0.0827	○
23	2013/4/4	-0.0528	○	2008/12/1	0.0819	
24	2014/10/31	-0.0525	○	1988/1/5	-0.0814	○
25	1999/6/21	-0.0489		2010/3/24	-0.0799	
26	2016/6/16	0.0486	○	1987/6/2	0.0797	
27	2016/7/26	0.0484		1985/2/1	-0.0796	
28	2003/9/22	0.0484		1995/5/31	-0.0785	
29	2022/4/28	-0.0482	○	2013/6/6	0.0753	
30	1988/10/11	0.0481		2008/11/12	0.0733	

Note: Negative values mean depreciation of the yen against the dollar.

while others are unpredictable and thus surprising. An announcement of monetary policy is one of those news events affecting exchange rate movements. Some monetary policies are predictable and thus unsurprising, whereas other monetary policies are unpredictable and thus surprising. Central banks, whether intentionally or unintentionally, are core players who generate large surprising shocks in the foreign exchange market.

Table 3 displays the most surprising 30 events recorded in the yen-dollar exchange market. In the Tokyo market, six surprising events occurred on the very days of the BOJ's Monetary Policy Meetings (MPM). Remarkably, these six announcements were all given in the course of the QQE under the command of Governor Kuroda. In particular, the introduction of QQE were announced on April 4, 2013, and its expansion on October 31, 2014. In the New York market, four surprising events occurred on the meeting days of FOMC of the Federal Reserve. These meetings were held in the context of the Plaza Agreements and of the Global Financial Crisis.

As the ranking lists show, surprising news are often tied with historical events and thus imprinted deeply on people's mind. There is no doubt that financial markets were strongly impressed by those events. This may be one of the reasons that the BOJ's policy during the Kuroda term is characterized as surprise policy by the media. The media's criticism, however, might depend too heavily on the impression of a few striking events. A statistically formal test is necessary for a fair evaluation of the BOJ's policy during the Kuroda term.

6. Statistical Tests for Surprise Policy

In this section, we test each BOJ governor for surprise policy, based on the surprise data obtained in Section 4. To begin with, we give a brief explanation of the test procedure to see whether BOJ governors conducted surprise policy or not. Using this procedure, we present statistical evidence that indicates that the BOJ resorted to surprise policy strongly during the Kuroda term. Note that the test procedure is applicable to any central bankers. We test Fed chairs and compare them with BOJ governors. Lastly, we conduct a robustness check with regard to a value of wedge ρ.

6.1. The test procedure

We say that a central bank conducts surprise policy, if surprise occurs on its policy meeting days more frequently than usual. We pick up policy meeting days in the sample to see how often surprise occurs on those days. To do so, we match the dates of surprise obtained in the previous section with the dates of MPM held at the BOJ and with those of FOMC of the Federal Reserve.

Define an occurrence rate of surprising policy statements on policy meeting days during governor i's term of office as follows.

$$R_i^{S/D} \equiv \frac{\#\ of\ surprising\ policy\ statements}{\#\ of\ governor\ i's\ policy\ meeting\ days}. \tag{19}$$

We say that governor i employs surprise policy, if $R_i^{S/D}$ is much higher than $R_T^{S/D}$ (= 4.4%), which is the occurrence rate of surprise in the unlimited sample of the Tokyo market obtained in the previous section. For the New York market, we use $R_N^{S/D}$ (= 5.2%) as a corresponding value, since $R_T^{S/D} \neq R_N^{S/D}$ as shown in the previous section. To be formal, we define the null hypothesis and the alternative hypothesis as follows.

$$H_0\colon\ R_i^{S/D} = R_T^{S/D}; \tag{20}$$

$$H_1\colon\ R_i^{S/D} > R_T^{S/D}. \tag{21}$$

If we reject the null, governor i conducts surprise policy.

We compute the p-value by the following formula.

$$p\text{-}\ value \equiv \sum_{S \le k} \binom{D}{k} \left(R_T^{S/D}\right)^k \left(1 - R_T^{S/D}\right)^{D-k}, \tag{22}$$

where $\binom{D}{k}$ is a binomial coefficient denoting the number of combinations of k elements out of a set of D elements. D and S are given by the denominator and the numerator of $R_i^{S/D}$ in equation (19), respectively. If the p-value is smaller than a certain significance level, we reject the null hypothesis and conclude that governor i uses surprise policy.

Define $R_i^{S/P}$ and $R_i^{P/D}$ for governor i as follows.

$$R_i^{P/D} \equiv \frac{\#\ of\ public\ information\ policy\ statements}{\#\ of\ governor\ i's\ policy\ meeting\ days}; \tag{23}$$

$$R_i^{S/P} \equiv \frac{\#\ of\ surprising\ policy\ statements}{\#\ of\ public\ information\ policy\ statements}. \tag{24}$$

Note that $R_i^{S/D} \equiv R_i^{S/P} \times R_i^{P/D}$. Thus, we can evaluate governor i's policy stance in detail by conducting binomial tests on $R_i^{S/P}$ and $R_i^{P/D}$ with null and alternative hypotheses similar to those of $R_i^{S/D}$. In so doing, we compare $R_i^{P/D}$ with $R_T^{P/D}$ (= 8.2%) for BOJ governors or with $R_N^{P/D}$ (= 7.8%) for Fed chairs, and we compare $R_i^{S/P}$ with $R_T^{S/P}$ (= 53.9%) for BOJ governors or with $R_N^{S/P}$ (= 66.3%) for Fed chairs.

Table 4
Test of surprise policy for BOJ governors

	MPM	Hayami	Fukui	Shirakawa	Kuroda
# of governor i's policy meeting days (D)	375	88	74	78	98
# of public information policy statements (P)	56	12	7	12	14
# of surprising policy statements (S)	32	5	4	4	13
$R^{P/D}$	14.9% ***	13.6% *	9.5%	15.4% **	14.3% **
$R^{S/D}$	8.5% ***	5.7%	5.4%	5.1%	13.3% ***
$R^{S/P}$	57.1%	41.7%	57.1%	33.3%	92.9% ***

Notes: ρ = 1%. ***, **, and * indicate 1%, 5%, and 10% significance, respectively.

If $R_i^{S/D} > R_m^{S/D}$ for $m \in \{T, N\}$, we say that governor i conducts surprise policy. This condition is satisfied if $R_i^{P/D} > R_m^{P/D}$ and/or $R_i^{S/P} > R_m^{S/P}$. In the former case, governor i may not intentionally conduct surprise policy. It is a consequence of governor i's providing information to improve communication with market participants, which increases opportunities of generating surprise as a by-product. In the latter case, however, governor i may not consciously remove surprising factors from policy statements, which suggests that governor i conducts surprise policy. Taking these arguments into consideration, we use the following terminology.

$$\text{Surprise policy: } R_i^{S/D} > R_m^{S/D}; \tag{25}$$

$$\text{Weak surprise policy: } R_i^{P/D} > R_m^{P/D} \text{ and } R_i^{S/D} > R_m^{S/D}; \tag{26}$$

$$\text{Strong surprise policy: } R_i^{S/P} > R_m^{S/P} \text{ and } R_i^{S/D} > R_m^{S/D}. \tag{27}$$

Note that there can be surprise policy that is both weak and strong and that there can be surprise policy that is neither weak nor strong.

6.2. Test results for the BOJ

Table 4 provides the relevant information about BOJ's MPM and presents the results of binomial tests of all MPMs as a whole and each governor for surprise policy. In our sample, the BOJ had 375 MPMs in total, out of which 32 meetings have surprising effects, i.e., $R_{MPM}^{S/D}$ = 8.5%. The result of a binomial test indicates $R_{MPM}^{S/D} > R_T^{S/D}$ at the 1% significance level. Thus, the BOJ has employed surprise policy over the 40 years since 1984 on average. To investigate where this result comes from, we decompose $R_{MPM}^{S/D}$ into the two factors: $R_{MPM}^{P/D}$= 14.9% and $R_{MPM}^{S/P}$= 57.1%. Based on the results of binomial tests, we accept $R_{MPM}^{S/P} = R_T^{S/P}$, but $R_{MPM}^{P/D} > R_T^{P/D}$ at the 1% significance level. Therefore, the BOJ has conducted weak surprise policy on average.

As is discussed in the introduction, we are motivated by the question of whether BOJ implemented surprise policy during the Kurda term, as criticized by the media. Note that the number of MPMs has increased substantially since the Hayam term. The reason is that the revised Bank of Japan Law, which was enforced on April 1, 1998, required the BOJ to be accountable more than ever.[11] In the following discussion, we focus on the four BOJ governors appointed under the new Bank of Japan Law: Governors Hayami, Fukui, Shirakawa, and Kuroda.[12] Based on the result of binomial tests of $R_i^{S/D}$, we accept $R_{Kuroda}^{S/D} > R_T^{S/D}$ at the 1% significance level, while we cannot reject the null for the other three governors. This result supports media's criticism that the BOJ employed surprise policy during the Kuroda term.[13]

We can make further statistical inference by examining $R_i^{P/D}$ and $R_i^{S/P}$ for each governor. Based on the result of binomial tests on $R_i^{P/D}$, we accept $R_i^{P/D} > R_T^{P/D}$ except for the Fukui term at the 10% significance level. This is consistent with the argument for all MPMs as a whole. Based on the result of binomial tests on $R_i^{S/P}$, we accept $R_i^{S/P} = R_T^{S/P}$ for many governors, which is also consistent with the argument for all MPMs as a whole. An exception is the Kuroda term, during which we have $R_{Kuroda}^{S/P} > R_T^{S/P}$ at the 1% significance level. Governor Kuroda was unique in that the BOJ conducted strong surprise policy during his term of office.

6.3. Test results for the Fed

We can conduct a similar analysis for the Fed. As shown in Table 5, the FOMC had 411

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[11] To be precise, the BOJ increased the number of regularly-scheduled monetary policy meetings in January 1998, but later decreased it from 14 to 8 times a year in January 2016.

[12] We exclude Governor Ueda from the current discussion since his term was not over at the time of writing.

[13] Though not presented in Table 4, with the Kuroda term divided into two, we have $R_{Kuroda}^{S/D} > R_T^{S/D}$ for the first term, but $R_{Kuroda}^{S/D} = R_T^{S/D}$ for the second term. Thus, it is likely that media's image of Kuroda's BOJ was formed during his first term.

Table 5

Test of surprise policy for Fed chairs

	FOMC	Greenspan	Bernanke	Yellen	Powell
# of governor i's policy meeting days (D)	411	205	81	33	58
# of public information policy statements (P)	39	14	9	6	6
# of surprising policy statements (S)	27	9	8	5	3
$R^{P/D}$	9.5%	6.8%	11.1%	18.2% **	10.3%
$R^{S/D}$	6.6%	4.4%	9.9% *	15.2% **	5.2%
$R^{S/P}$	69.2%	64.3%	88.9%	83.3%	50.0%

Notes: ρ = 1%. ***, **, and * indicate 1%, 5%, and 10% significance, respectively.

meetings during the sample period, out of which 27 meetings had surprising effects, i.e., $R_{FOMC}^{S/D}$= 6.6%. Based on the result of a binomial test, we accept $R_{FOMC}^{S/D} = R_N^{S/D}$. That is, the Fed did not implement surprise policy on average over the sample. We also evaluate $R_{FOMC}^{P/D}$= 9.5% and $R_{FOMC}^{S/P}$= 69.2% by binomial tests and show that we cannot reject $R_{FOMC}^{P/D} = R_N^{P/D}$ nor $R_{FOMC}^{S/P} = R_N^{S/P}$. The former is in contrast with the result we obtained for the BOJ and may be quite natural since the Fed had no amendment of law as the BOJ had. Note also that 155 meetings out of 342 were held during Chair Greenspan's term of office; thus, the results for all FOMC meetings as a whole reflect its character strongly.

Table 5 includes the results of $R_i^{P/D}$, $R_i^{S/P}$, and $R_i^{S/D}$ for each chair. The Fed began releasing policy statements after every FOMC meeting in February 1994. Thus, we focus on the four Fed chairs: Greenspan, Bernanke, Yellen, and Powell. The results of binomial tests indicates that two chairs out of four have a possibility of conducting surprise policy: $R_{Bernanke}^{S/D} > R_N^{S/D}$ at the 10% significance level and $R_{Yellen}^{S/D} > R_N^{S/D}$ at the 5% significance level. As for Chair Yellen, we have $R_{Yellen}^{S/P} = R_N^{S/P}$, but $R_{Yellen}^{P/D} > R_N^{P/D}$ at the 5% significance level. Thus, the Fed's policy during her term is characterized as weak surprise policy. As for Chair Bernanke, we have $R_{Bernanke}^{S/P} = R_N^{S/P}$ and $R_{Bernanke}^{P/D} = R_N^{P/D}$. Despite of his large-scale asset purchases and other novel policy measures introduced in face of the Global Financial Crisis, the evidence of surprise policy is not that strong. Lastly, we emphasize that we have had $R_i^{S/P} = R_m^{S/P}$ for $m \in \{T, N\}$ most of the time since the late 1990s both in the U.S. and in Japan except for the Kuroda term. Kuroda's BOJ stands out in the history of central banking due to its strong dependence on surprise policy.

Table 6

Tests of surprise policy for BOJ governors with various values of ρ

ρ		MPM	Hayami	Fukui	Shirakawa	Kuroda
0.0%	$R^{P/D}$	51.7%	53.4%	39.2%	53.8%	55.1%
	$R^{S/D}$	39.5%	38.6%	31.1%	37.2%	41.8%
	$R^{S/P}$	76.3%	72.3%	79.3%	69.0%	75.9%
0.5%	$R^{P/D}$	22.4% ***	20.5%	13.5%	26.9% ***	22.4% **
	$R^{S/D}$	13.3% ***	10.2%	8.1%	12.8%	18.4% ***
	$R^{S/P}$	59.5%	50.0%	60.0%	47.6%	81.8% **
1.0%	$R^{P/D}$	14.9% ***	13.6% *	9.5%	15.4% **	14.3% **
	$R^{S/D}$	8.5% ***	5.7%	5.4%	5.1%	13.3% ***
	$R^{S/P}$	57.1%	41.7%	57.1%	33.3%	92.9% ***
1.5%	$R^{P/D}$	6.7% **	3.4% *	4.1%	2.6%	11.2% ***
	$R^{S/D}$	4.5% ***	2.3%	4.1%	0.0%	9.2% ***
	$R^{S/P}$	68.0% *	66.7%	######	0.0%	81.8% **
2.0%	$R^{P/D}$	5.1% **	5.7% *	2.7%	1.3% **	7.1% **
	$R^{S/D}$	2.9% **	3.4%	0.0%	0.0%	6.1% ***
	$R^{S/P}$	57.9%	60.0%	0.0%	0.0%	85.7% *

Notes: ρ = 1%. ***, **, and * indicate 1%, 5%, and 10% significance, respectively.

6.4. Robustness of the test results

We assume $\rho = 1.0\%$ as a benchmark in the analysis above. As pointed out in the previous section, as ρ increases, the number of identified public information events decreases. The test results are also affected by the choice of ρ. We investigate how robust the test results are by changing the value of ρ. Table 6 shows the results of binomial tests for the BOJ with ρ = {0.0%, 0.5%, 1.0%, 1.5%, 2.0%}. We have $R^{S/D}_{Kuroda} > R^{S/D}_{T}$ at the 1% significance level with $\rho \geq$ 0.5%. We also have $R^{P/D}_{Kuroda} > R^{P/D}_{T}$ at the 5% significance level with $\rho \geq$ 0.5%; $R^{S/P}_{Kuroda} > R^{S/P}_{T}$ at the 10% significance level with $\rho \geq$ 0.5%. These results indicate that the test results for the Kuroda term obtained above is robust.

Table 7 presents the results of binomial tests for the Fed. We have $R^{S/D}_{Bernanke} > R^{S/D}_{N}$ at the 10% significance level with ρ = 0.5 and 1.0%. However, the inequality disappears with $\rho \geq$ 1.5%. We have $R^{S/D}_{Yellen} > R^{S/D}_{N}$ at the 1% significance level with $\rho \leq$ 0.5% and also at the 5% significance level with ρ = 1.0%. However, the inequality disappears with $\rho \geq$ 1.5%. These results indicate that the test results concerning Chairs Bernanke and Yellen obtained above are not necessarily robust. We are not very sure that they conducted surprise policy.

Table 7

Tests of surprise policy for Fed chairs with various values of ρ

ρ		FOMC	Greenspan	Bernanke	Yellen	Powell
0.0%	$R^{P/D}$	65.2% *	62.9%	58.0%	87.9% ***	69.0%
	$R^{S/D}$	52.3%	47.3%	49.4%	75.8% ***	56.9%
	$R^{S/P}$	80.2%	75.2%	85.1%	86.2%	82.5%
0.5%	$R^{P/D}$	22.6% ***	18.5%	23.5%	30.3% *	25.9% *
	$R^{S/D}$	16.3% **	15.1%	18.5% *	30.3% ***	22.4% **
	$R^{S/P}$	72.0%	81.6%	78.9%	100.0% **	86.7%
1.0%	$R^{P/D}$	9.5%	6.8%	11.1%	18.2% **	10.3%
	$R^{S/D}$	6.6%	4.4%	9.9% *	15.2% **	5.2%
	$R^{S/P}$	69.2%	64.3%	88.9%	83.3%	50.0%
1.5%	$R^{P/D}$	6.8% **	5.9%	7.4%	6.1%	5.2%
	$R^{S/D}$	4.1%	3.9%	2.5%	6.1%	1.7%
	$R^{S/P}$	60.7%	66.7%	33.3%	100.0%	33.3%
2.0%	$R^{P/D}$	5.1% **	3.9%	8.6% **	0.0%	1.7%
	$R^{S/D}$	2.7%	1.5%	3.7%	0.0%	1.7%
	$R^{S/P}$	52.4%	37.5%	42.9%		100.0%

Notes: ρ = 1%. ***, **, and * indicate 1%, 5%, and 10% significance, respectively.

7. Effects of Surprise Policy on the Phillips Curve

According to our conjecture, the BOJ's ultimate purpose of generating surprise was to get rid of deflationary mindset and raise inflation rates. We have shown in the preceding section that the BOJ during the Kuroda term succeeded in generating surprise in the yen-dollar exchange market by its policy statements. In this section, we proceed to explore the next question of whether surprising policy statements were effective for raising inflation rates in the Japanese economy. This is an important question, since its answer leads to an evaluation of the QQE conducted for a decade during the Kuroda term. To reach a final answer, we need thorough research in various aspects. The following analysis is one of such attempts. Below, we conduct estimation analysis in a monthly basis. The sample spans over the period of July 1984 to March 2024.

7.1. The specification of the Phillips curve

To see the effects of surprise policy on inflation rates, we estimate the Phillips curve augmented with surprise.

$$I_t = \tilde{\alpha}\tilde{I}_{t-1} + \alpha_0 + \beta_0\hat{Y}_{t-1} + \gamma_0\hat{X}_{t-1} + \Sigma_i\alpha_i D_{it-1} + \Sigma_i\beta_i D_{it-1}\hat{Y}_{t-1} + \Sigma_i\gamma_i D_{it-1}\hat{X}_{t-1}$$
$$+\Sigma_i\delta_{Oi}\tilde{S}_{Oit-1} + \Sigma_i\delta_{Yi}\tilde{S}_{Yit-1}\hat{Y}_{t-1} + \Sigma_i\delta_{Xi}\tilde{S}_{Fit-1}\hat{X}_{t-1} + \varepsilon_t, \quad (28)$$

where I_t is an inflation rate in Japan. $\tilde{I}_t$ is a 12-month backward moving average of inflation rates. $\hat{Y}_t$ is the output gap in Japan. $\hat{X}_t$ is the real effective exchange rate gap of Japan and captures overall inflation pressures from international trades of goods and services. A rise in $\hat{X}_t$ means the appreciation of the yen in a real term against the currencies of Japan's foreign trade partners. D_{it} is a dummy variable of governor i, taking on 0 before his appointment and 1 since his appointment. Subscript i indicates a governor appointed after the revision of the Bank of Japan Law: 1 = Hayami, 2 = Fukui, 3 = Shirakawa, 4 = Kuroda in his first term, 5 = Kuroda in his second term, and 6 = Ueda. Governors Sumita, Mieno, and Matsushita are pooled as one group and indicated by subscript 0.

$\tilde{S}_{Oit}$, $\tilde{S}_{Yit}$, and $\tilde{S}_{Xit}$ indicate the effects of surprise generated by policy statements during governor i's term on the trend inflation rates, the slope of the Phillips curve, and the pass-through, respectively. Denote the measure of surprise (%) generated during governor i's term by S_{it}. We construct it by summing up the absolute value of the magnitude of surprise observed each month without distinguishing depreciation surprise and appreciation surprise. Furthermore, we take into consideration the persistence of surprise effects and formulate it in the following autoregressive models:

$$\tilde{S}_{Oit} = \phi_{Oi}\tilde{S}_{Oit-1} + S_{it}; \quad (29)$$

$$\tilde{S}_{Yit} = \phi_{Yi}\tilde{S}_{Yit-1} + S_{it}; \quad (30)$$

$$\tilde{S}_{Xit} = \phi_{Xi}\tilde{S}_{Xit-1} + S_{it}, \quad (31)$$

where ϕ_{Oi}, ϕ_{Yi}, and ϕ_{Xi} indicate persistence of surprise on the trend inflation rates, the slope of the Phillips curve, and the pass-through, respectively.

When all the gaps close and all the shocks die out, the inflation rate converges to the following value:

$$\frac{\alpha_0 + \Sigma_i \alpha_i D_{it-1} + \Sigma_i \delta_{Oi} \tilde{S}_{Oit-1}}{1 - \tilde{\alpha}}. \tag{32}$$

This is called the t*rend inflation rate* and viewed as a measure of inflation expectations (see Kaihatsu and Nakajima, 2015). The trend inflation rate consists of three components. We are interested in the last component ($\delta_{Oi}\tilde{S}_{Oit}$) particularly, since it reflects an impact of surprise on trend inflation. The second component ($\alpha_i D_{it-1}$) is thought of as capturing impacts of all the other events that occurred during governor i's term, including the effects of expected monetary policy, domestic fiscal policy, overseas economic and financial developments, natural disasters inside and outside of the economy, and so on.

Gathering the coefficients of $\hat{Y}_{t-1}$ and $\hat{X}_{t-1}$, we have

$$\beta_0 + \Sigma_i \beta_i D_{it-1} + \Sigma_i \delta_{Yi} \tilde{S}_{Yit-1}; \tag{32}$$

$$\gamma_0 + \Sigma_i \gamma_i D_{it-1} + \Sigma_i \delta_{Xi} \tilde{S}_{Xit-1}, \tag{33}$$

These are the slope of the Phillips curve and the pass-through, respectively. We are particularly interested in the last components ($\delta_{Yi}\tilde{S}_{Yit-1}$, $\delta_{Xi}\tilde{S}_{Xit-1}$), since they measure impacts of surprise on the slope of the Phillips curve and the pass-through. The second components ($\beta_i D_{it-1}$, $\gamma_i D_{it-1}$) capture impacts of all the other events that occurred during governor i's term.

7.2. The data and estimation strategy

As a measure of inflation, we use the so-called *core CPI* inflation rate, i.e., the year-on-year monthly inflation rate of the consumer price index excluding fresh foods (Figure 10).[14] This is the inflation measure that has been used by Japanese economists in the estimation of the Phillips curve and is one of the inflation measures that the BOJ has watched traditionally to judge the overall developments of inflation rates in Japan. Officially, the BOJ targets the inflation rate of the unadjusted overall consumer price index currently. Nonetheless, the BOJ shifted its focus to the so-called *core core CPI*

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[14] We subtract the increments in the consumption tax rate from the monthly core CPI inflation rate, that is, 3% from April 1989 to March 1990; 2% from April 1997 to March 1998; 3% from April 2014 to March 2015; and 2% from October 2019 to September 2020.

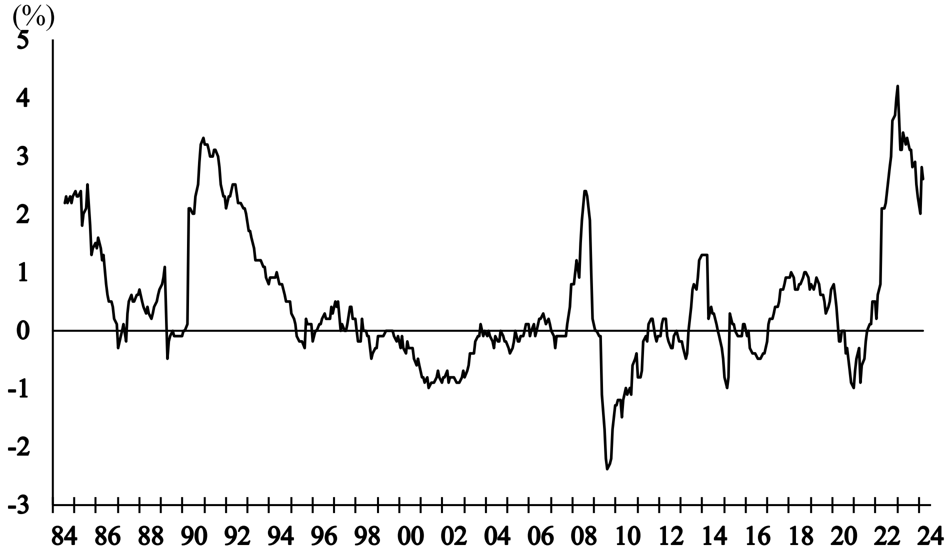

Fig 10. CPI inflation

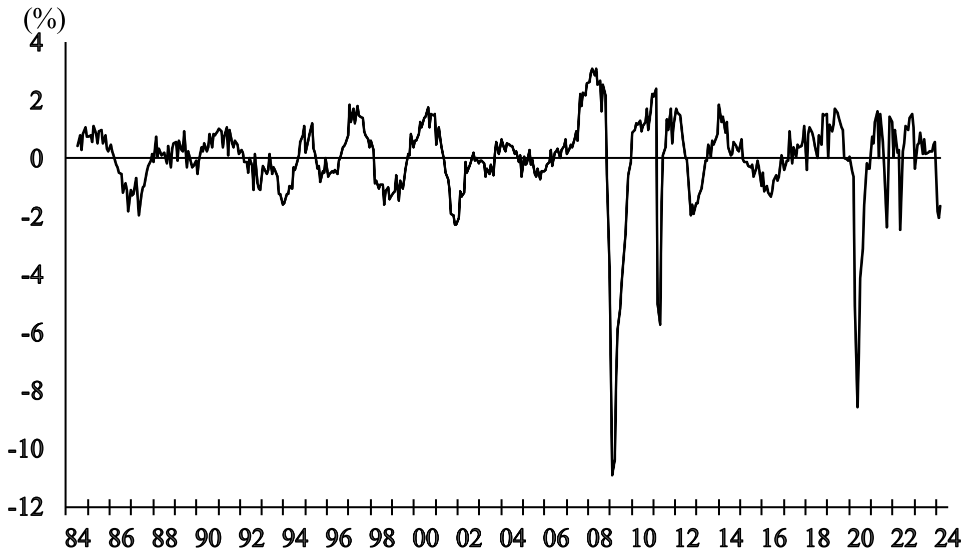

Fig 11. Output gap

inflation rate, which excludes food and energy from the core CPI inflation rate, in the course of the QQE. We use the traditional core CPI in the analysis below, not the unadjusted nor the core core CPI.

We have no monthly measure of overall real activities for the Japanese economy that covers both manufacturing and no-manufacturing industries. We use a simplified

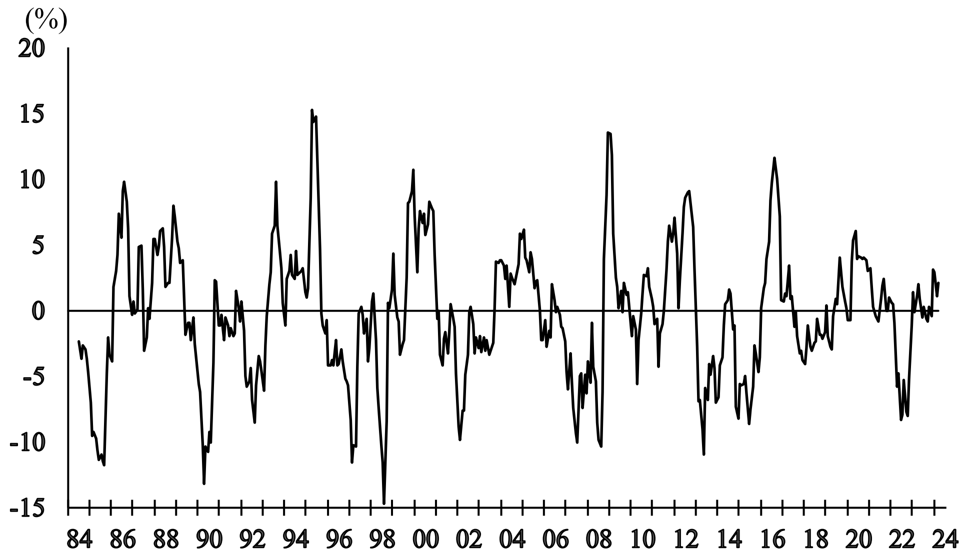

Fig 12. Foreign exchange rate gap

version of Kamada and Masuda's (2001) estimation method to calculate the monthly output gap, based on the unemployment rate and the capacity utilization rate of capital, which are available in a monthly basis (Figure 11). We explain the estimation procedure briefly in Appendix C. To check its correctness, we aggregate the resulting monthly output gap into a quarterly basis and compare it with the GDP-based quarterly output gap there.

We apply the Hodrick-Prescott filter to the natural log of the real effective exchange rate and use its cyclical portion as the gap measure of the foreign exchange rate (Figure 12). For this purpose, we do not use the yen-dollar exchange rate, which was used for measuring surprise in the previous sections. The reason is that by doing so, we fail to incorporate all the effects of changes in the prices of goods and services imported from all over the world on the consumer prices. In contrast, the real effective exchange rate includes the exchange rates of all trading partners and reflects all the effects of international trades on the consumer prices.

To estimate $\tilde{\alpha}$, α's, β's, γ's, δ's, and ϕ's in equation (28), we use the following two step procedure: First, we give a certain value to each of ϕ's and calculate $\tilde{S}$'s according to equations (29) to (31); second, we estimate $\tilde{\alpha}$, α's, β's, γ's, and δ's by the ordinary least squares and calculate R^2. We give a new value for each of ϕ's and repeat the above procedure. We choose the combination of $\tilde{\alpha}$, α's, β's, γ's, δ's, and ϕ's that maximizes R^2 as the final estimation result of equation (28). We are particularly interested in the estimates of δ's and ϕ's, since they capture the effectiveness of surprise policy for changing the structure of the Phillips curve and its duration, respectively.

Some caveats are in order here. First, for ease of computation, we assume that ϕ's can take only on the three values of 0, 0.5, and 1 in estimation. In theory, a more granular domain can be assumed instead. Here we point out the existence of a severe trade-off between the granularity of estimates and the time consumed for estimation. Second, we focus on surprise generated by the four governors (five terms) of Hayami, Fukui, Shirakawa, and Kurda (his first and second terms) in estimation.

7.3. The result of estimations

The estimation result of equation (28) is displayed in Table 8. We have a particular interest in the effects of surprise generated by policy statements during the Kuroda term on trend inflation. During his first and second terms, the effects of surprise are estimated to be positive (δ_{O4}, $\delta_{O5} > 0$) and significant at the 1% level. Furthermore, those effects are permanent ($\phi_{O4} = \phi_{O5} = 1$). This suggests that the BOJ's surprise policy during the Kuroda term was useful for raising inflation rates through trend inflation.

We can calculate the level of trend inflation and its variation during each governor's term of office by substituting the estimation result into equation (32). Table 9 shows the result. During Governor Kuroda's first term, the trend inflation rose about by 1.5 percentage points and turned to be positive from around a zero percent level.[15] This tendency was reinforced during his second term. It is remarkable that these developments were driven mostly by surprise policy.

During other governors' terms, however, t surprise policy had no positive and significant effects on trend inflation, as shown in Table 8. For instance, during the Shirakawa term, the effects of surprise policy were significant at the 1% level, but

[15] This result is consistent with that of Kaihatsu and Nakajima (2015), although they do not distinguish monetary policy's surprise effects from other effects.

Table 8

Estimation results of the Phillips curve

	Estimate	Std error			Estimate	Std error			Estimate
$\tilde{\alpha}$	0.8075	(0.0322)	**						
α_0	0.1017	(0.0503)	***						
β_0	0.1470	(0.0495)	***						
γ_0	-0.0403	(0.0068)	***						
α_1	0.0122	(0.2723)	***	δ_{O1}	-0.0517	(0.0466)		ϕ_{O1}	1
α_2	0.4478	(0.1595)	***	δ_{O2}	-0.1017	(0.1182)		ϕ_{O2}	1
α_3	0.1629	(0.2960)		δ_{O3}	-0.2361	(0.0435)	***	ϕ_{O3}	0.5
α_4	-0.5703	(0.2163)	***	δ_{O4}	0.0273	(0.0083)	***	ϕ_{O4}	1
α_5	-0.2656	(0.1298)	**	δ_{O5}	0.1367	(0.0312)	***	ϕ_{O5}	1
α_6	-1.0469	(0.2853)	***						
β_1	-0.2199	(0.0991)	**	δ_{Y1}	0.1164	(0.1376)		ϕ_{Y1}	0.5
β_2	0.0622	(0.2452)		δ_{Y2}	0.1261	(0.0841)		ϕ_{Y2}	1
β_3	-0.2515	(0.1103)	**	δ_{Y3}	0.1876	(0.0321)	***	ϕ_{Y3}	0.5
β_4	0.1369	(0.1765)		δ_{Y4}	-0.0045	(0.0098)		ϕ_{Y4}	1
β_5	-0.1249	(0.1884)		δ_{Y5}	0.1957	(0.1330)		ϕ_{Y5}	0
β_6	-0.0602	(0.1631)							
γ_1	0.0840	(0.0303)	***	δ_{X1}	-0.0072	(0.0065)		ϕ_{X1}	1
γ_2	-0.0299	(0.0421)		δ_{X2}	0.0250	(0.0186)		ϕ_{X2}	1
γ_3	-0.1147	(0.0452)	**	δ_{X3}	0.0026	(0.0009)	***	ϕ_{X3}	1
γ_4	-0.1004	(0.0391)	**	δ_{X4}	0.0023	(0.0014)		ϕ_{X4}	1
γ_5	-0.0978	(0.0458)	**	δ_{X5}	-0.0101	(0.0091)		ϕ_{X5}	1
γ_6	0.2105	(0.1220)	*						
				R^2	0.8444				

Notes: 1=Hayami, 2=Fukui, 3=Shirakawa, 4=Kuroda1, 5=Kuroda2, and 6=Ueda.

***, **, and * mean 1%, 5%, 10% significance, respectively.

negative ($\delta_{O3} < 0$) and only temporarily ($\phi_{O3} < 1$). Consequently, though other shocks had positive and significant effects ($\alpha_1,\ \alpha_2 > 0$), the trend inflation rate was negative or around zero percent during the fifteen years of the Hayami, Fukui, and Shirakawa terms, as shown in Table 9.

The slope of the Phillips curve is one of the most important policy parameters for central banks to affect the developments of inflation rates. If surprise policy steepens

Table 9

Contributions of surprise and no-surprise

(a) The trend inflation (%)

	Governor	Observation month	Level[1] Total	Level[1] Surprise policy	Level[1] Others	Change Total	Change Surprise policy	Change Others
0		1998/03	0.53	0.00	0.53	-	-	-
1	Hayami	2003/03	-1.49	-2.08	0.59	-2.02	-2.08	0.06
2	Fukui	2008/04	-0.73	-3.65	2.92	0.76	-1.57	2.33
3	Shirakawa	2013/03	0.11	-3.65	3.76	0.85	0.00	0.85
4	Kuroda I	2018/04	1.61	0.80	0.80	1.49	4.46	-2.96
5	Kuroda II	2023/04	6.46	7.04	-0.58	4.86	6.24	-1.38

(b) The slope of the Phillips curve

	Governor	Observation month	Level[1] Total	Level[1] Surprise policy	Level[1] Others	Change Total	Change Surprise policy	Change Others
0		1998/03	0.15	0.00	0.15	-	-	-
1	Hayami	2003/03	-0.07	0.00	-0.07	-0.22	0.00	-0.22
2	Fukui	2008/04	0.36	0.37	-0.01	0.44	0.37	0.06
3	Shirakawa	2013/03	0.11	0.37	-0.26	-0.25	0.00	-0.25
4	Kuroda I	2018/04	0.11	0.23	-0.13	-0.01	-0.14	0.14
5	Kuroda II	2023/04	-0.02	0.23	-0.25	-0.12	0.00	-0.12

(c) The pass-through

	Governor	Observation month	Level[1] Total	Level[1] Surprise policy	Level[1] Others	Change Total	Change Surprise policy	Change Others
0		1998/03	-0.04	0.00	-0.04	-	-	-
1	Hayami	2003/03	-0.01	-0.06	0.04	0.03	-0.06	0.08
2	Fukui	2008/04	0.03	0.02	0.01	0.04	0.07	-0.03
3	Shirakawa	2013/03	0.11	0.10	0.01	0.08	0.08	0.00
4	Kuroda I	2018/04	0.09	0.17	-0.09	-0.03	0.07	-0.10
5	Kuroda II	2023/04	-0.10	0.08	-0.18	-0.19	-0.09	-0.10

Note: (1) the level at the end of each governor's term of office;

the slope of the Phillips curve, central banks can use it to strengthen the traditional transmission mechanism of monetary policy. Table 8 shows that no significant effects are observed on the slope during the two terms of Governor Kuroda. That is, the BOJ failed to restore the sensitivity of inflation rates to a change in the output gap during the Kuroda term. With regard to other governors, during the Shirakawa term for instance, surprise effects steepened the slope significantly at the 1% level ($\delta_{Y3} > 0$) but only temporarily ($\phi_{Y3} < 1$), while other shocks were negative and significant at the 5% level

($\beta_3 < 0$). As a result, the slope was flattened almost completely during his term.

Although the BOJ insisted that inflation induced by the depreciation of the yen was not what it pursued by the QQE, it is a fact that high pass-through facilitates importing inflation from overseas economies. Table 9 shows that the pass-through was strengthened during the two terms of Governor Kuroda. The rise in the pass-through, however, was induced by shocks other than surprise ($\gamma_4,\ \gamma_5 < 0$), as displayed in Table 8. We do not see any significant effects of surprise policy on the pass-through.

8. Concluding Remarks

This paper examined the BOJ's monetary policy from the viewpoint of surprise, with a special focus on Governor Kuroda's policies, which were often characterized as surprise policy and criticized by the media. We employed a formal statistical method to show that the BOJ conducted strong surprise policy during the Kuroda term. This paper also examined the effects of surprise policy on the structure of the Phillips curve. The regression analysis showed that surprise generated by the BOJ during the Kuroda term had significant effects on trend inflation, or inflation expectations of households and entrepreneurs, but had no significant effects on the slope of the Phillips curve and the pass-through of the foreign exchange rate.

Some comments are in order here. First, this paper focused on the yen-dollar exchange market to identify the timing and magnitude of surprise. We can do a similar analysis based on other financial markets if data exist on high-, low-, and close-prices for those markets. For instance, we can identify surprise in stock markets and trace policy effects from a wider perspective. Second, in this paper, we focused on direct instantaneous effects of surprises on inflation rates. However, surprise may affect inflation indirectly by influencing the output and foreign exchange rates, which in turn influence inflation rates. This possibility is examined by estimating a VAR model and simulating the impulse response function. Furthermore, inflation rates may rise a long time after deflation mindset is removed by surprise. We can search for an optimal lag of surprise in the Phillips curve to verify this possibility. We leave these extensions as future works. For the identification of those long-run effects, we will need more sophisticated econometric methods than conducted in this paper.

Since 2022, the global economy has suffered high inflation rates, due to strong demands in advanced countries after the Covid-19 pandemic and the surge in energy prices caused by the Russian invasion of Ukraine. In Japan, inflation rates rose beyond the BOJ's target rate of 2%. Nonetheless, the BOJ kept low interest rates under the QQE and justified this decision by pointing out that the domestic demand was not so strong as to pull up inflation rates in Japan. To contain high inflation, however, the Fed and the ECB raised their policy rates one after another. As a result, interest rate differentials between Japan and other countries widened and thus induced a large depreciation of the yen, which strengthened inflationary pressure on the Japanese economy. A primary task entrusted to Governor Ueda, who succeeded Kuroda, was to cease the QQE and normalize the Japanese yield curve. A policy shift may generate surprise, whether it is intended or unintended. The analysis of the Ueda term will lead to providing further understanding of surprise policy. We postpone this interesting policy analysis as a future task.

Appendix A. Introduction to Candlestick Charts

A candlestick chart was invented in the 18th's Japan and, since its introduction by Nison (1991), has been used all over the world as a tool for predicting future developments of

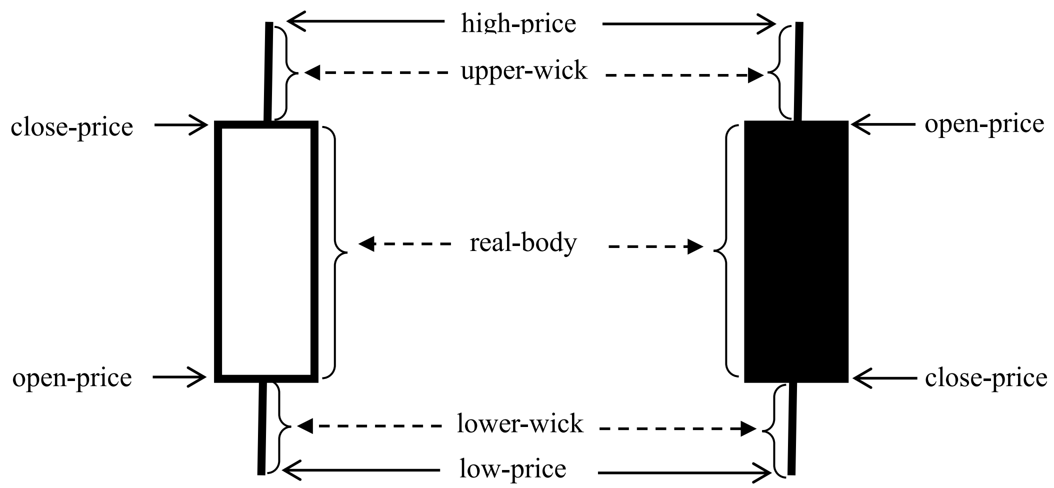

Fig. A1. Candlestick charts.

asset prices. Figure A1 displays two typical candlestick charts. A white box is called a *real body*, whose lower and higher ends indicate *open-price* and *close-price*, respectively. As for a black box, lower and higher ends indicate *close-price* and *open-price*, respectively. A bar attached on the higher end of the box is called an *upper-wick* and its end is called a *high-price* which indicates the highest price observed during a day. A bar attached on the lower end of the box is called a *lower-wick* and its end is called a *low-price* which indicates the lowest price observed during a day. Technical analysts believe that certain sequential patterns of candlestick charts signal a profit-making opportunity, while academic researchers educated under the efficient market hypothesis are basically skeptical of the predictability of technical analysis.

Appendix B. The Yen-Dollar Exchange Rate Outside Tokyo and New York

In this appendix, we examine the seriousness of misidentification of public information due to ignoring changes in the yen-dollar exchange rate while the Tokyo and New York markets are closed. We, however, have no candlestick charts of the Singapore, London, and EU markets and thus cannot apply the same empirical strategy to those markets.

Instead, we use the following alternative strategy. Recall that the candlestick charts of the Tokyo and New York markets include the open and close prices of the dollar in the two markets. Using those prices, we calculate the yen-dollar exchange rate changes in the following four cases: (a) from the Tokyo open-price to the Tokyo close-price; (b) from the Tokyo close-price to the New York open-price; (c) from the New York open-price to the New York close-price; (d) from the New York close-price to the Tokyo open-price.

The data are found in the Nikkei NEEDS, covering the period of March 1, 1995 to May 15, 2024.[16] We calculate the root mean squared changes for each of the four cases above. The result is 0.38% in case (a), 0.30% in case (b), 0.42% in case (c), and 0.18% in case (d). Rate changes are larger while the Tokyo and New York markets are open

[16] The data span only over the period of March 1, 1995 to May 15, 2024 due to the lack of the open-price data in the Tokyo market.

(cases (a) and (c)) than while they are closed (cases (b) and (d)).[17] It is also true, however, that the size of rate changes after the Tokyo market closes and before the New York market opens is too large to ignore (case (b)). Note that in this examination, we do not discriminate the effects of public information and those of private information.

Appendix C. The Monthly Output Gap

In a quarterly-basis analysis, we have the data on the gross domestic products in Japan and can calculate the output gap, which is defined as the deviation rate of the actual output from the potential, or $\ln Y_t - \ln Y_t^*$. We obtain it as the cyclical component of $\ln Y_t$ by the Hodrick-Prescott filter.

In a monthly-basis analysis, since we do not have the data on the gross domestic products, we calculate the output gap in the following way. Denote the labor and capital by L and K, respectively, and their capacity utilization by z_L and z_K, respectively. With the total factor productivity of A, the output is given by

$$Y_t = A_t (z_{Lt} L_t)^{0.6} (z_{Kt} K_t)^{0.4}, \tag{C1}$$

where we assume that the Japanese labor share is 60%. Similarly, the potential output is given by

$$Y_t^* = A_t (z_{Lt}^* L_t)^{0.6} (z_{Kt}^* K_t)^{0.4}, \tag{C2}$$

where * denotes the potential level. Then the output gap is given by

$$\hat{Y}_t = \ln Y_t - \ln Y_t^* = 0.6(\ln z_{Lt} - \ln z_{Lt}^*) + 0.4(\ln z_{Kt} - \ln z_{Kt}^*), \tag{C3}$$

where $\ln z_{Kt} - \ln z_{Kt}^*$ is obtained as the cyclical component of the log of capacity utilization of capital obtained by the Hodrick-Prescott filter. Note that z_{Lt}, the capacity utilization of labor, is $1 - u_t$, where u_t is the unemployment rate. Thus, $\ln z_{Lt} - \ln z_{Lt}^*$ is obtained as the cyclical component of $-u_t$.

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[17] The root mean squared changes of the yen-dollar exchange rate in case (d) is much smaller than that observed in the other cases, since no major market are open in the interval after the end of the New York market and before the open of the Tokyo market.

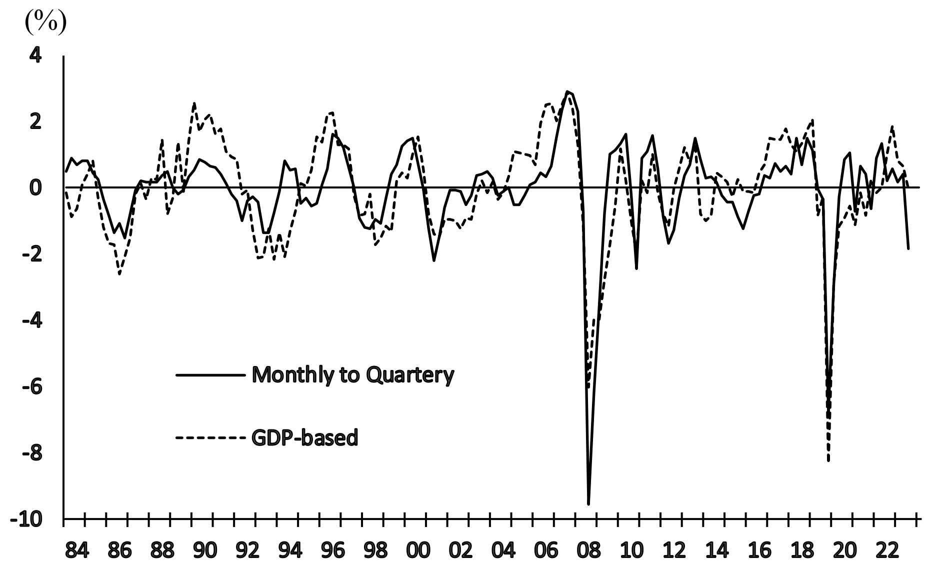

Fig C1. GDP-based and monthly-to-quarterly output gap

To see the consistency of the monthly and quarterly output gap, we transform the monthly output gap into a quarterly basis and compare it with the quarterly output gap, as in Figure C1. The two measures of the output gap are close to each other during the sample period, although the monthly output gap underestimates the quarterly output gap temporarily in the early 1990s.

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