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The Bank of Japan's Large-Scale Government Bond Purchases and the Formation of Long-Term Interest Rates

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The Bank of Japan's Large-Scale Government Bond Purchases and the Formation of Long-Term Interest Rates [*]

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Abstract

This paper quantitatively examines the effects of the Bank of Japan's (BOJ's) purchases of Japanese government bonds (JGBs) – especially the large-scale purchases since the introduction of Quantitative and Qualitative Monetary Easing in 2013 – on the formation of long-term interest rates in Japan using time series analysis. The results can be summarized as follows. First, having quantified the effect of BOJ JGB purchases taking market participants' expectations about the future path of such purchases into account, we find that the effect of JGB purchases on interest rates has been driven by the increase in JGB holdings (i.e., the *stock* effect), which affects market participants' risk allocation, rather than by the daily conduct of JGB purchases (i.e., the *flow* effect), which affects supply and demand in the secondary market. Second, in addition to the flow and stock effects, the Yield Curve Control framework introduced in September 2016 had the effect of restraining interest rate increases when long-term interest rates approached the upper bound of the announced range. This effect tended to be larger when the BOJ took countermeasures and market participants expected such countermeasures. Finally, our analysis of interest rates at different maturities suggests that the framework of government bond purchases and Yield Curve Control had an effect on interest rates across a wide range of maturities, and that the recent large-scale monetary easing had the effect of pushing down the entire yield curve.

JEL Classification: G12, E44, E52, E58

Keywords: unconventional monetary policy, long-term interest rates, government bond purchases, flow effect, stock effect, announcement effect, yield curve control

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These tools are often referred to as "unconventional" or "nonstandard" policies. Since I will argue that these tools should become part of the standard toolkit, I will refer to them here as "new" or "alternative" monetary tools. — Ben S. Bernanke [2020]

QE has now been used numerous times in the past two decades for extended periods when the policy rate was at the effective lower bound, so I would say it is no longer unconventional. — Christopher J. Waller [2024]

1. Introduction

The Bank of Japan (BOJ) introduced Quantitative and Qualitative Monetary Easing (QQE) in April 2013, under which it has conducted large-scale purchases of Japanese government bonds (JGBs); in September 2016, the BOJ introduced the framework of yield curve control (YCC), in which it sets both short-term and long-term interest rates as policy rate targets, and since then has conducted JGB purchases in a more flexible manner in order to achieve its long-term interest rate target; in this sense, YCC is a form of quantitative easing. Subsequently, in March 2024, the BOJ decided to end the framework of QQE with YCC, judging that achieving the price stability target of 2 percent in a sustainable and stable manner had come in sight. During this period, the BOJ's JGB purchases had pushed down the yield curve as a whole, which had a positive impact on economic activity and prices.[1]

The history of quantitative easing as a monetary policy tool – not only in Japan, but worldwide – dates back to March 19, 2001, when the BOJ introduced its Quantitative Easing Policy (QEP). At that time, the BOJ changed its operating target for money market operations from the short-term interest rate (uncollateralized overnight call rate) to a quantitative indicator, the outstanding balance of the current accounts at the BOJ, and introduced forward guidance that the policy would continue until the year-on-year change in the consumer price index (excluding fresh food) registered stably a zero percent or an increase year on year. However, the quantitative expansion at that time mainly focused on the supply of short-term funding. During this period, the BOJ also decided to increase the amount of its long-term government bond purchases, but this was not intended to push down long-term interest rates but to facilitate the smooth supply of short-term funding (Shirakawa [2002] and Ueda [2005]).[2] Subsequently, the U.S., Europe, and other major

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[1] For details on the impact on economic activity and prices, see the BOJ's September 2016 "Comprehensive Assessment" and the March 2021 "Assessment for Further Effective and Sustainable Monetary Easing." In the March 2021 Assessment, the simulation results show that the BOJ's large-scale monetary easing boosted the level of real GDP by about 0.9 to 1.3 percent on average and the year-on-year rate of change in consumer prices by about 0.6 to 0.7 percentage point on average. Moreover, developing a variant of the BOJ's macroeconomic model (Q-JEM) that takes the term structure of interest rates into account, Izawa et al. [2024] reassessed the results of the present paper and obtained more or less the same results.

[2] During the global financial crisis, following the collapse of Lehman Brothers in September 2008, the BOJ increased its purchases of long-term JGBs, but regarded this as a measure to ensure financial market stability.

advanced economies increasingly conducted government bond and risky asset purchases in response to the global financial crisis of the late 2000s, and such "unconventional" tools have come to be regarded as part of the standard toolkit (Bernanke [2020] and Waller [2024]). Against this background, there has been a growing body of academic research about the effects on long-term interest rates, with recent studies reaching a consensus that central bank holdings of government bonds have the effect of pushing down long-term interest rates (Bernanke [2020] and BIS [2023]).

Following these developments in academic research, this paper conducts an empirical analysis of the effect of the BOJ's JGB purchases, especially the large-scale purchases since the introduction of Quantitative and Qualitative Monetary Easing in 2013, on the formation of long-term interest rates in Japan. The main results are threefold. First, quantifying the effect of JGB purchases taking market participants' expectations about the future path of the purchases into account, we find that the effect of JGB purchases on interest rates has been driven by the increase in JGB holdings (i.e., the stock effect), which affects market participants' risk allocation, rather than by the daily conduct of JGB purchases (i.e., the flow effect), which affects supply and demand in the secondary market. Second, quantifying the effect of the YCC framework introduced in September 2016 using a model incorporating the probability that the targeted long-term yield will exceed the YCC range implied by option prices as a proxy, we find that, in addition to the flow and stock effects described above, the framework of QQE with YCC had the effect of restraining interest rate increases when long-term interest rates approached the upper bound of the announced range. This effect tended to be larger when the BOJ took countermeasures and market participants expected such countermeasures. Third, examining interest rates at different maturities, we find that government bond purchases and YCC had an effect on interest rates across a wide range of maturities, and that the large-scale monetary easing since 2013 had the effect of pushing down the entire yield curve.

The remainder of this paper is organized as follows. Sections 2 and 3 provide an overview of previous studies about the effect of government bond purchases and YCC and how they affect the formation of long-term interest rates in Japan. In Section 4, we construct a time series model consistent with the literature and quantify the effect on long-term interest rates and the entire yield curve. Section 5 concludes.

2. The Effect of Government Bond Purchases

How central bank purchases of government bonds work

Central bank purchases of government bonds affect the formation of long-term interest rates in the market through various channels as discussed in previous studies. It is useful to review these channels based on the following three perspectives.[3] The first perspective focuses on policy actions and distinguishes between (i) the *flow effect*, in which central bank purchases of government bonds in the secondary market affect the supply and demand for government bonds at the time of purchase, and (ii) the *stock effect*, in which the central bank's large-scale holdings of government bonds have a persistent effect on the supply of government bonds in the market. This classification is useful in practice because it corresponds to the actual policy measures (monthly purchases of government bonds and holdings on the balance sheet). The second focuses on the mechanism through which the effects materialize: (i) the *liquidity effect* through the impact on market liquidity, (ii) the *portfolio-balance effect* through the impact on market participants' risk allocation, and (iii) the *signaling effect* through the impact on market participants' expectations about the future path of short-term interest rates implied by the stance of monetary policy. In academic research, many studies construct a structural model based on such theoretical concepts. The third perspective focuses on the timing that the effects materializes and distinguishes between (i) the *implementation effect*, which occurs when the central bank purchases take place and holdings arise, and (ii) the *announcement effect*, which arises prior to implementation as market participants anticipate future central bank actions and incorporate them into prices.[4] Many previous studies have pointed to the importance of the announcement effect and highlight that it is important to consider market expectations when interpreting the empirical results of event studies.

It should be noted that these perspectives are not mutually exclusive and that the different effects are closely related. It is therefore useful to consider these perspectives together when examining the effects of government bond purchases (Chart 1).[5] For example, the *flow effect* of government bond purchases is closely related to the *liquidity effect* and the *implementation effect*, as it could push down yields on the targeted assets by affecting supply and demand at the time of the purchases. In addition, the *stock effect* of government bond holdings is linked to the *portfolio balance effect*, which refers to the effect that central bank purchases of government bonds from market participants (i.e., economic agents other than the central bank) push down long-term interest rates by absorbing duration risk from the market. Finally, the *announcement effect* affects the

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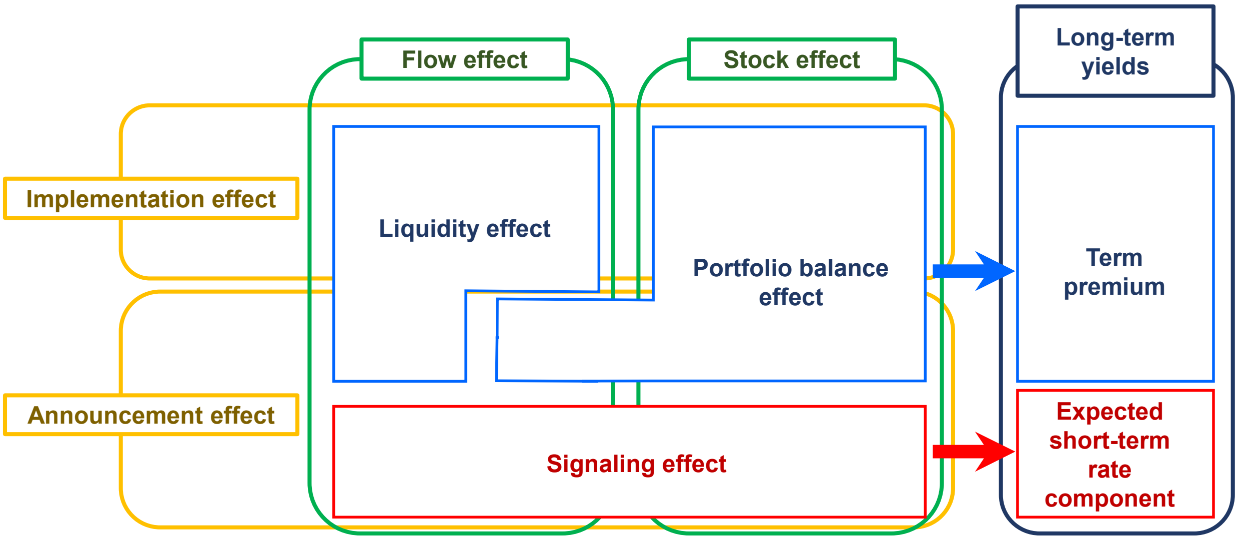
[3] There are numerous other studies providing an overview of the different channels from a similar perspective to this paper. Example from the 2000s include Eggertsson and Woodford [2003], Bernanke et al. [2004], Ueda [2005], Ugai [2007], and Shirakawa [2008], while more recent examples are the studies by Bernanke [2020], Aoki [2023], BIS [2023], Logan [2024], and Schnabel [2024].

[4] "Announcement" here refers not only to the actual announcements of policy measures by central banks, but also to all actions and information by central banks that could affect the formation of market expectations.

[5] As shown in Chart 1, there is a considerable overlap between these classifications, and it is important to note that since there are no strict definitions, the meaning of each classification may differ somewhat depending on the author and situation. In addition to the channels shown in Chart 1, other channels have been pointed out, such as the default risk channel and the inflation channel, which operate through changes in expectations regarding economic developments. See, for example, Krishnamurthy and Vissing-Jorgensen [2011] and Ueda [2012].

formation of long-term interest rates through announcements of future purchases and holdings of government bonds, which may indicate the future stance of monetary policy. If the effects of future purchases and holdings are priced in, the *liquidity* and *portfolio balance effects* may arise before the actual purchases and holdings materialize. If this also creates market expectations that monetary easing will continue further, the effect on interest rates is called the *signaling effect*.[6]

Chart 1. Effects of Government Bond Purchases on Long-term Yields



Signaling effect and the expected short-term rate component of long-term yields

Based on these considerations, many studies examine long-term yields by constructing term structure models of interest rates and decomposing long-term interest rates into two components: (i) the average of the expected future path of short-term interest rates (the expected short-term rate component), and (ii) the term premium, which is obtained as the residual. The reason why this approach is widely used is that, by definition, the expected short-term rate component captures the signaling effect, while the term premium captures other effects, so that the results are easy to interpret.

Chart 2 shows the expected short-term rate component of long-term JGB yields estimated using the term structure model of interest rates proposed by Imakubo and

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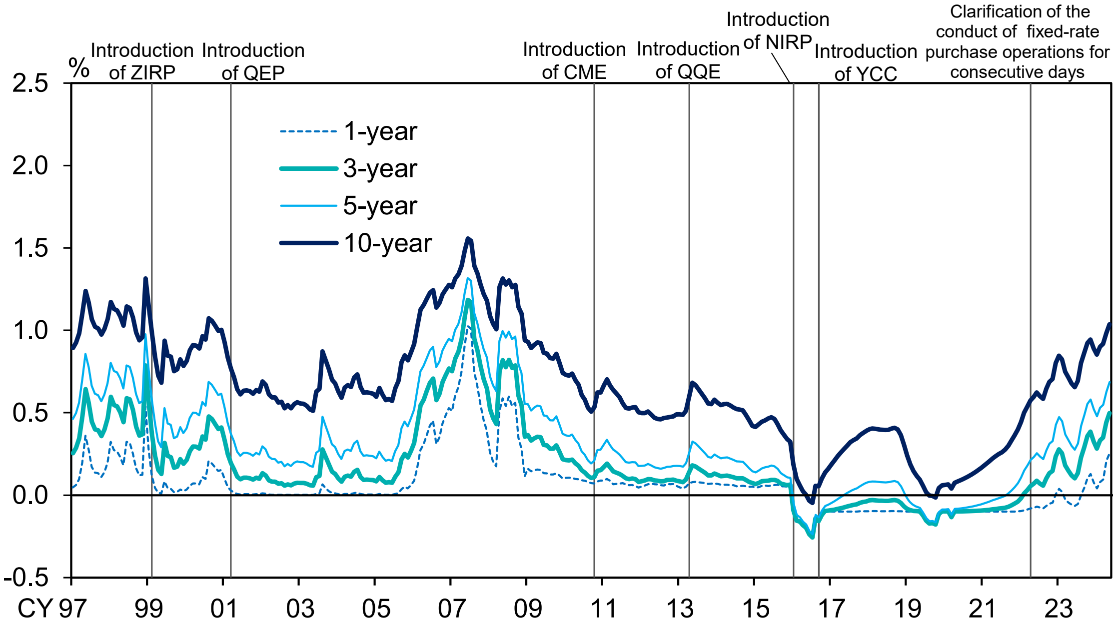
[6] The reason why central banks have started to adopt unconventional monetary policy tools is that short-term interest rates fell near the effective lower bound, so that it was no longer possible to conduct monetary policy using the conventional tool, namely, setting short-term interest rates. Trying to push down medium- and long-term interest rates by creating the expectation that short-term interest rates will remain low for a long period (through the *signaling effect*) through forward guidance on short-term interest rates and/or a quantitative commitment is something that has been discussed since the introduction of Japan's zero interest rate policy in 1999. See, for example, Fujiki and Shiratsuka [2002], Bernanke and Reinhart [2004], and Ueda [2005].

Nakajima [2015], which takes the effective lower bound on short-term interest rates into account.[7]

Chart 2. The Expected Short-term Rate Component of Long-term Yields, by Maturity



Note: Latest data are as of May 2024.
Source: Bloomberg.

As pointed out in previous studies (e.g., Ugai [2007] and Aoki [2023]), the expected short-term rate component of long-term JGB yields declined significantly after the introduction of quantitative easing in the 2000s, suggesting that a *signaling effect* was seen through the impact on market expectations that the future path of short-term interest rates would remain low for a long period.[8] On the other hand, the expected short-term rate component tended to rise after the introduction of Comprehensive Monetary Easing

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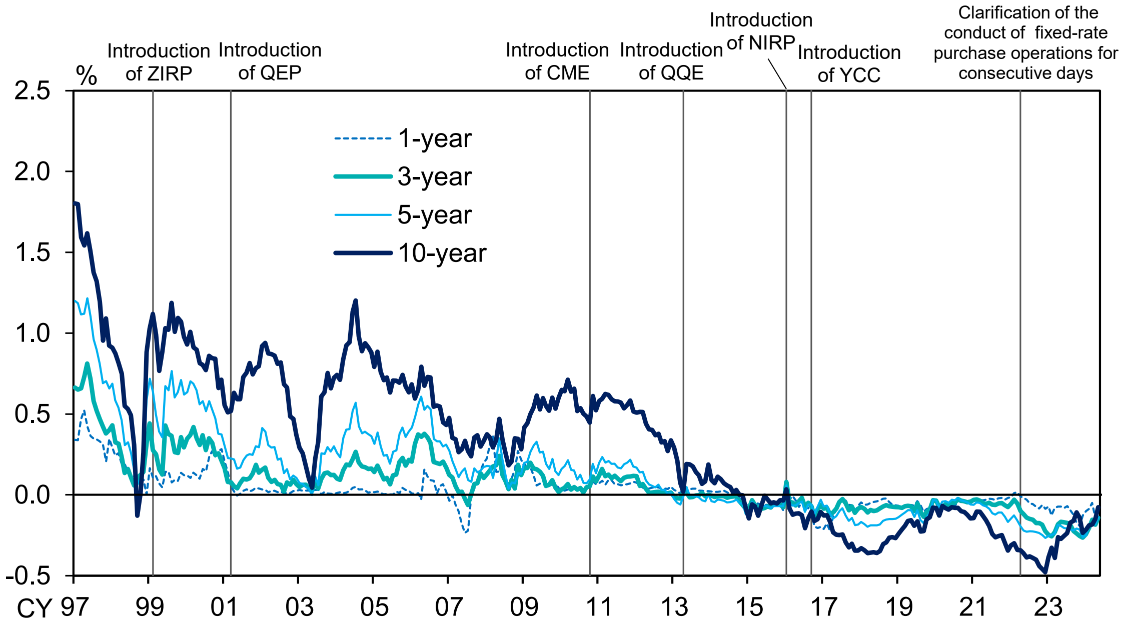
[7] In this paper, we make the following two changes to the term structure model of interest rates proposed by Imakubo and Nakajima [2015] in light of the recent situation. First, since the effective lower bound on short-term interest rates has declined since the introduction of the negative interest rate policy, the lower bound from January 2016 onward is regarded to be whichever is the lowest at a particular point in time of the following rates: the 1- to 6-month overnight index swap (OIS) rates, the call rate, and minus 0.1 percent, which is the interest rate applied to policy rate balances in the current accounts held by financial institutions at the BOJ (i.e., the effective lower bound is assumed to change over time). Second, while 2-, 5-, 7-, and 10-year JGB yields were used to estimate the term structure model, since the 10-year JGB yield was the target of YCC, the 15-year yield is used instead of the 10-year yield to ensure that the estimation results are not directly affected by YCC.

[8] After the introduction of the zero interest rate policy (ZIRP) in 1999, the expected short-term rate component also declined due to the policy duration effect induced by the commitment to "continue the zero interest rate policy until deflationary concerns are dispelled" (see for example, Fujiki and Shiratsuka [2002] and Ugai [2007]). For the U.S., Bauer and Rudebusch [2014] and others report that Large-Scale Asset Purchases (LSAPs) had the effect of pushing down long-term interest rates through their impact on the expected short-term rate component.

(CME) and Quantitative and Qualitative Monetary Easing (QQE). This may be due to the effects of the rise in U.S. interest rates seen at that time and expectations of an improvement in economic activity as a result of monetary easing.

Chart 3 shows that the term premium of long-term JGB yields hovered at around 0.5 to 1.0 percent with some large swings during the 2000s, then declined significantly from around 2012. It has remained in negative territory for the past decade since 2015. This result is in line with the findings of previous studies. Oda and Ueda [2007] find that government bond purchases before 2005 did not have any statistically significant effect through the term premium but did have the effect of reducing long-term interest rates by leading to a decline in the expected short-term rate component. One of the reasons why, as pointed out by Shirakawa [2002], is that the BOJ's JGB purchases were still small relative to the overall amount outstanding in the market. On the other hand, many studies suggest that the large-scale JGB purchases since 2013 have had the effect of reducing long-term yields, mainly due to a decline in the term premium (e.g., Fukunaga et al. [2015], Katagiri and Takahashi [2017], and Sudo and Tanaka [2021]).

Chart 3. Term Premium of Long-term Yields, by Maturity



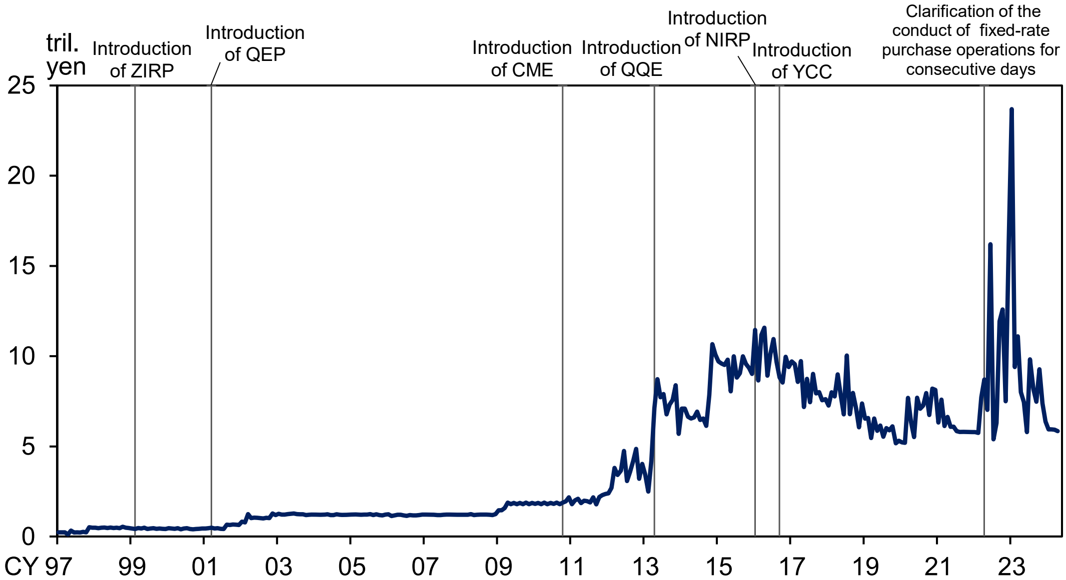
Note: Latest data are as of May 2024.
Source: Bloomberg.

Flow effect of government bond purchases

As shown in Chart 4, the BOJ's monthly JGB purchases increased after (i) the introduction of the QEP in March 2001 and (ii) the introduction of CME in October 2010, but the size of the increases was small compared to (iii) the increase after the introduction of QQE in

April 2013 and (iv) the expansion of QQE in October 2014. Subsequently, (v) after the introduction of YCC in September 2016, the amount of JGB purchases declined somewhat, but (vi) when interest rates came under upward pressure in domestic and foreign financial markets from 2022 onward. JGB purchases increased again substantially, partly due to the conduct of fixed-rate purchase operations at the upper bound of the targeted fluctuation range of YCC.

Chart 4. BOJ's Monthly JGB Purchases



Note: Latest data are as of April 2024. Based on the settlement day of operations.
Source: Bank of Japan.

The large purchases through fixed-rate purchase operations conducted frequently since 2022 are the result of the clarification of how the BOJ would conduct fixed-rate purchase operations for consecutive days and the upper bound of the targeted fluctuation range, decided at the April 2022 Monetary Policy Meeting.

Apart from these unique circumstances under YCC, central bank purchases of government bonds generally have a liquidity effect by directly affecting supply and demand in the secondary market at the time of purchase. In particular, BOJ purchases of longer-maturity JGBs since 2013 may have had the effect of pushing down long-term interest rates to some extent. Previous studies have also pointed out that the effects of asset purchases, including purchases not only of government bonds but also a wide range of other assets, tend to be stronger in times of stress, when liquidity and risk premiums increase.[9]

[9] For example, BIS [2023] highlights the effects of central banks' large-scale asset purchases in the wake of the COVID pandemic, while Logan [2024] and Schnabel [2024] argue that the effects of asset purchases vary across economic and financial conditions. Regarding the effect of asset purchases on corporate bond

At the same time, however, previous studies have also pointed out that such liquidity effects are essentially temporary and limited to the targeted asset and/or its substitutes. For example, Bernanke [2020] points out that the liquidity effect should theoretically be short-lived, while various empirical results suggest that the effect of government bond purchases tends to be persistent, which is more consistent with the stock effect in theory. In this regard, Sudo and Tanaka [2021], using a dynamic stochastic general equilibrium model, show that in Japan the stock effect dominates the flow effect, accounting for more than 90 percent of the interest rate reduction effects. On the other hand, as pointed out in BIS [2023], when a central bank conducts government bond purchases, market participants pay attention to its stance with regard to purchases, which affects expectations with regard to the central bank's future monetary policy stance and government bond purchases and hence interest rate formation.

Stock effect of government bond holdings

When examining the effect of central bank government bond holdings (i.e., the stock effect) on long-term interest rates through the *portfolio balance effect*, there are three points to consider from a theoretical perspective. First, there are *preferred-habitat investors* who have preferences for specific maturities (Vayanos and Vila [2021]). In particular, pension funds and insurance companies, due to their liability structure, are not indifferent to the maturity structure of their assets and tend to prefer bonds with relatively long maturities. When the supply of longer-maturity bonds in the market decreases, imperfect substitution between bonds with different maturities pushes down long-term interest rates.[10] Second, the concept of *interest rate risk (duration risk)* is important for investors to manage their balance sheets (Krishnamurthy and Vissing-Jorgensen [2011]). The longer the maturity of a bond, the greater its interest rate risk. Therefore, central bank purchases of longer-maturity bonds have a larger effect on long-term interest rates than purchases of shorter-maturity bonds, even when the amounts purchased are the same.

Chart 5 shows the outstanding amount of JGBs held by economic agents. While the overall amount has been on an upward trend, holdings by the BOJ have increased substantially since the introduction of QQE in 2013, so that the share of BOJ holdings in the total amount outstanding has exceeded 40 percent since 2017 and recently reached around 50 percent. On the other hand, in terms of holdings by economic agents other than

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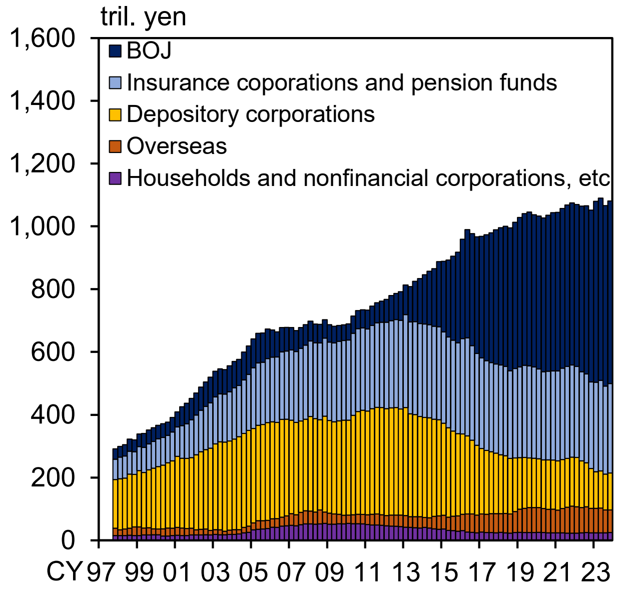
yields, some studies (e.g., Gilchrist and Zakrajšek [2013] and Gilchrist et al. [2021]) highlight the default risk channel, which refers to the effect of central banks' crisis response measures on credit risk premiums through the impact on market expectations with regard to an improvement in economic activity. As for corporate bond purchases in Japan, empirical findings by Ochi and Osada [2024] suggest that both the flow and stock effects of such purchases improve the functioning of corporate bond markets.

[10] A growing number of studies on the effects of central bank purchases of government bonds rely on the preferred-habitat model of Vayanos and Vila [2021], originally published in 2009. See, for example, Krishnamurthy and Vissing-Jorgensen [2011], Gagnon et al. [2011], and D'Amico and King [2013] for the United States, Altavilla et al. [2015] for Europe, and Fukunaga et al. [2015] for Japan.

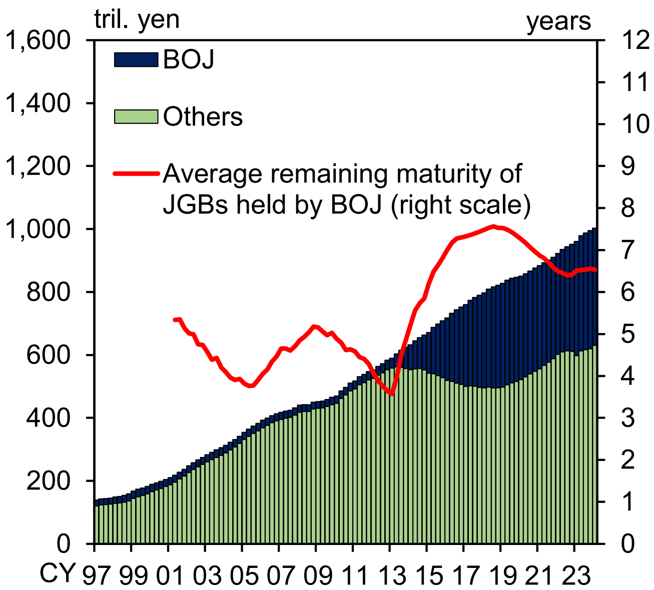
the BOJ, holdings by depository financial institutions as well as households and firms have been declining. Moreover, looking at the amount of JGBs outstanding on a risk-adjusted basis (i.e., the 10-year equivalent value) shows that the BOJ has absorbed interest rate risk from the market, as it has increased its purchases of longer-maturity JGBs since 2013 and the average duration of its holdings has increased substantially. That said, since 2019, the average duration of non-BOJ holdings has also increased, and the amount of interest rate risk in the rest of the JGB market has increased somewhat.

Chart 5. Total Amount of JGBs Outstanding, by Economic Agent

Par amount



Ten-year bond equivalent value (taking interest rate risk into account)

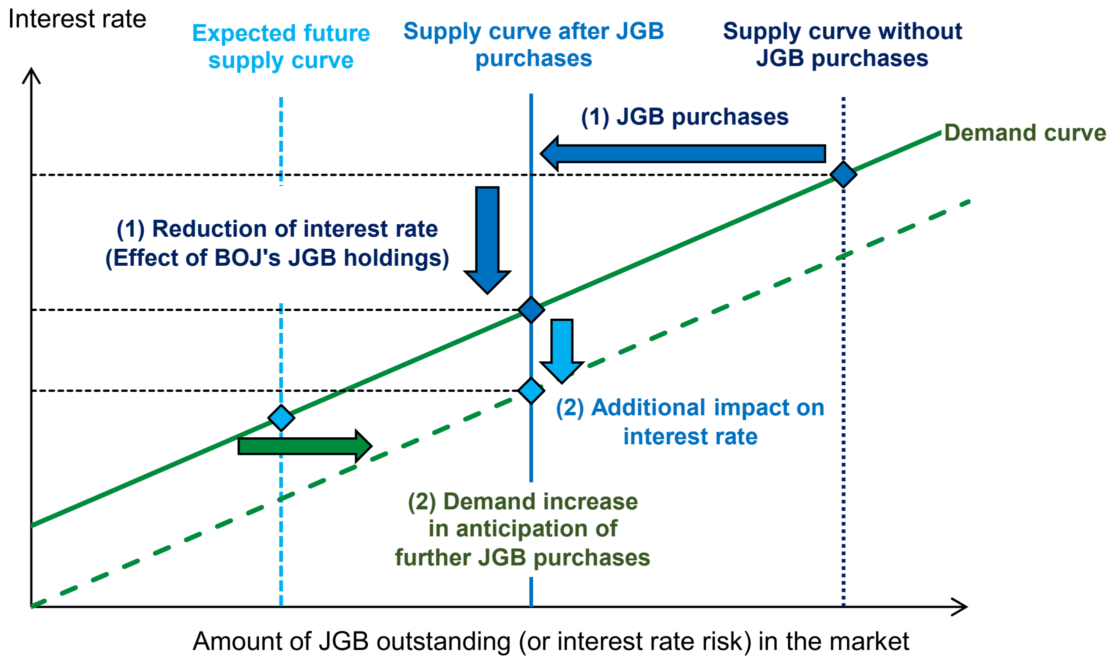


Notes: 1. The left chart shows the outstanding amount of JGB holdings in the *Flow of Funds Accounts* (on a market value basis). Treasury discount bills are not included before April 2010. Latest data are as of the October-December quarter of 2023.
2. Figures for the right chart are obtained by converting the amount outstanding of different maturities into the equivalent amount of 10-year bonds containing the same amount of interest rate risk. Latest data are as of the January-March quarter of 2024. Figures for the BOJ's JGB holdings prior to May 2001 are estimates based on certain assumptions (see Appendix A for details of the calculation method).

Source: Bank of Japan.

Third, government bond purchases have an *announcement effect* (e.g., Bernanke [2020]). That is, by shaping market participants' expectations about the future supply of government bonds, purchases affect long-term yields in a forward-looking manner. The demand-supply curve analysis in Chart 6 illustrates this point. As noted above, an increase in central bank holdings of government bonds reduces the amount of interest rate risk in the market and lowers long-term interest rates (term premiums) as market participants take on additional interest rate risk. Moreover, if market participants anticipate further purchases of JGBs by the BOJ in the future, the demand curve will shift so that the expected future decline in interest rates materializes in advance. In this case, the decline in interest rates due to the stock effect may occur before the actual purchases are made as a result of the announcement effect.

Chart 6. Stock Effect of Government Bond Holdings (Conceptual Illustration)



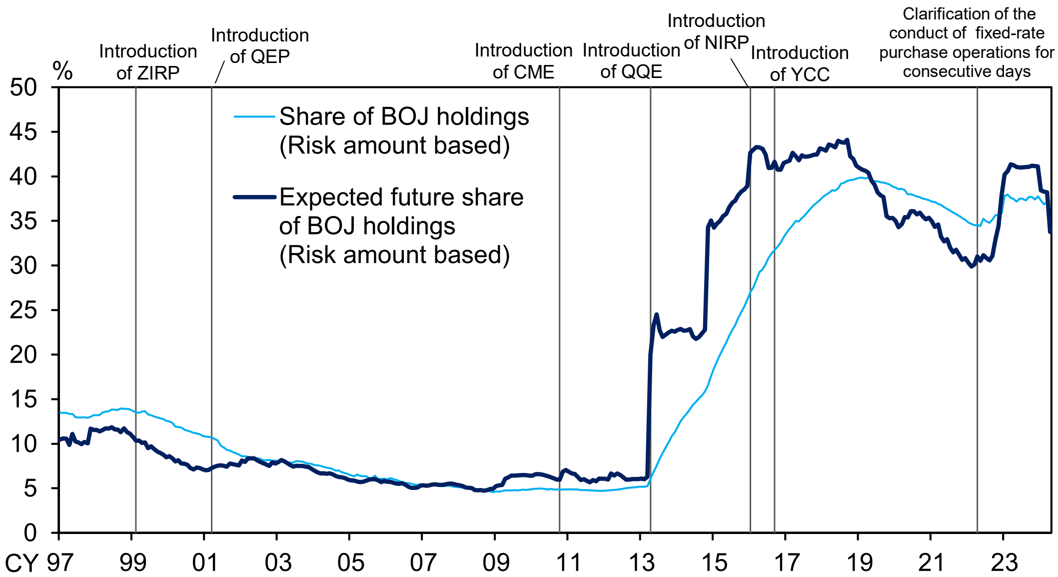
A number of studies have sought to quantify the stock effect of government bond holdings taking the announcement effect into account. Specifically, focusing on the United States, Li and Wei [2013] and Ihrig et al. [2018] empirically examine how announcement shocks with regard to the Federal Reserve's (Fed's) future Treasury holdings affect the U.S. term premium through market participants' expectations. These studies assume that (i) market participants anticipate the Fed's future Treasury holdings based on the expectation that the Fed will follow its announced purchase plan, and (ii) they also form expectations about outstanding Treasury securities in the rest of the market. The longer the Fed continues to purchase Treasury securities (i.e., the more open-ended the purchases are), the larger the effect of the Fed's announcement on long-term interest rates at the time of the announcement.[11] Another study along these lines is that by Chung et al. [2023], who develop a variant of the Fed's FRB/US macroeconomic model that assumes that the Fed follows a relatively mechanical rule in its Treasury purchases and incorporates a mechanism for how expected changes in the future size of the Fed's balance

[11] Li and Wei [2013] and Ihrig et al. [2018] use a similar framework to analyze the effects of the Fed's purchases of mortgage-backed securities (MBS) in addition to Treasury securities.

sheet affect the current term premium.[12] They then use the model to estimate the effect of the Fed's bond-purchase policy on market developments, economic activity, and prices.

Following these studies, in this paper we construct indicators of the *expected BOJ holdings of JGBs in the future* using certain assumptions in order to quantify the stock effect, taking the effect of market participants' expectations with regard to future developments into account.[13] Specifically, we assume that market participants anticipate future (two-year ahead) BOJ holdings of JGBs at each point in time based on the BOJ's actual and planned monthly purchases of JGBs. In addition, we make mechanical assumptions about the amount of JGB issuance during this period and calculate *the expected future share of BOJ holdings*, which is shown in Chart 7. The calculated future share rose sharply when QQE was introduced in April 2013. Thus, the expected share changes significantly at the time of policy announcements as market participants' expectations are incorporated ahead of actual changes in the share of JGB holdings.

Chart 7. Expected BOJ Holdings of JGBs (Share of Total, 10-year Equivalent)



Notes: See Appendix A for details on how the data are constructed. Latest data are as of April 2024.
Source: Bank of Japan.

In Section 4, we will quantify the effects of the BOJ's JGB purchases on long-term interest rates through the various channels discussed in this section, taking the effect through market participants' expectations into account. Such a quantitative assessment of the policy effects based on theoretical considerations will provide a useful perspective for

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[12] More concretely, the Fed's Treasury-purchase rule in Chung et al. [2023] is (i) that the Fed begins to expand its balance sheet when the federal funds rate reaches the effective lower bound of the short-term interest rate, and (ii) that the Fed begins quantitative tightening after a certain period of time after developments in economic activity and prices improve and the short-term interest rate is raised. Since the policy rule for the short-term interest rate depends on economic and inflation conditions, expectations with regard to future purchases of Treasury securities also depend on economic and inflation conditions.

[13] See Appendix A for details on how we construct the data.

drawing policy implications.

3. The Effect of Yield Curve Control

Developments in long-term interest rates under the YCC framework

QQE with YCC, introduced by the BOJ in September 2016, is a framework that promotes the formation of a market yield curve in line with the Guideline for Market Operations, which sets the short-term policy rate at minus 0.1 percent and the target 10-year JGB yield at *around zero percent*, through large-scale JGB purchases. With the introduction of YCC, the BOJ introduced *fixed-rate purchase operations* as a new tool that allows the BOJ to conduct operations to make the yield curve consistent with the Guideline for Market Operations when necessary, such as when interest rates rise sharply.

Although the BOJ did not explicitly state a targeted fluctuation range for the 10-year JGB yield under YCC from the introduction of YCC until July 2018, market participants perceived the range to be *around ±0.1 percent* based on the actual conduct of fixed-rate purchase operations and the fact that the yield in practice remained within this narrow range. Subsequently, when the BOJ decided on "Strengthening the Framework for Continuous Powerful Monetary Easing" in July 2018, it also allowed the targeted long-term yield to fluctuate up to *about double the previous fluctuation range of around ±0.1 percent*. In March 2021, when the BOJ decided to conduct "Further Effective and Sustainable Monetary Easing," it clarified the fluctuation range to be *around ±0.25 percent* and introduced "fixed-rate purchase operations for consecutive days" to strictly limit the upper bound of long-term interest rates when necessary.

Moreover, in early 2022, the rises in interest rates seen globally also put upward pressure on long-term yields in Japan, which rose to around 0.25 percent at that time. Under these circumstances, in April 2022, the BOJ decided to clarify the conduct of fixed-rate purchase operations for consecutive days, and decided to offer to purchase 10-year JGBs at *0.25 percent* through fixed-rate purchase operations every business day, unless there was a high probability that no bids would be submitted. Subsequently, the BOJ decided to increase flexibility in the conduct of YCC through the following intermittent steps: in December 2022, the fluctuation range was expanded to *±0.5 percent*; in July 2023, while using the fluctuation range of ±0.5 percent as reference, the target level at which fixed-rate purchase operations are offered was set at *1.0 percent*; and in October 2023, the BOJ decided to promote the formation of a yield curve consistent with the guideline through nimble responses, while using the upper limit of the long-term yield of 1.0 percent as reference.[14] In March 2024, as noted earlier, the BOJ judged that the YCC framework had fulfilled its role and changed the monetary policy framework, as achieving the price stability target of 2 percent in a sustainable and stable manner had come into

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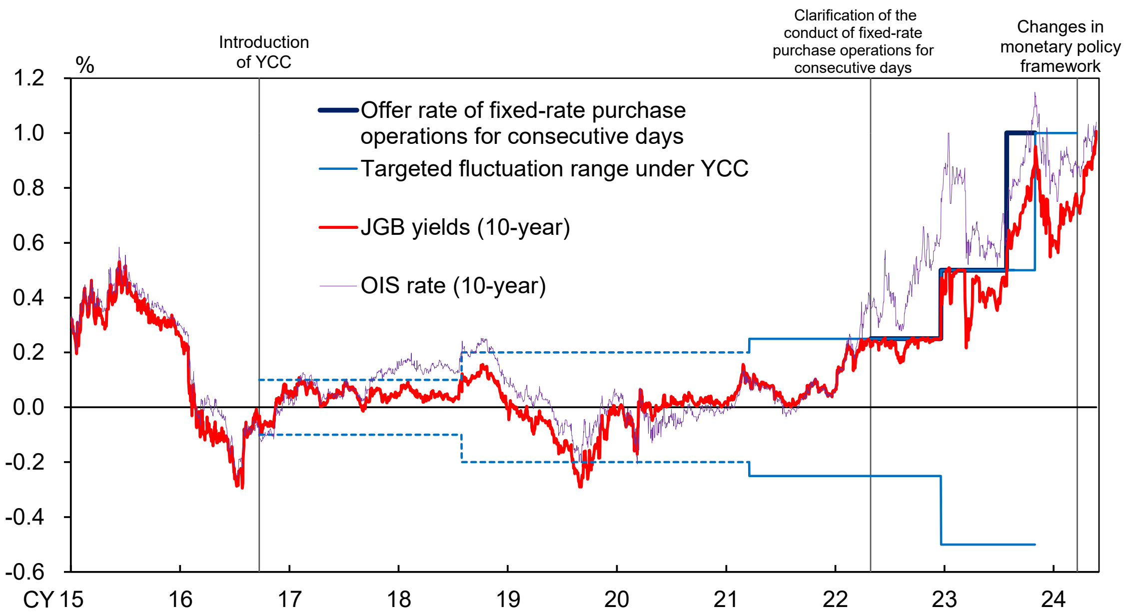
[14] In October 2023, the BOJ decided to determine the offer rate for fixed-rate purchase operations at each offer, taking market rates and other factors into account.

sight.

Chart 8 presents long-term interest rates during this period. While they were generally within the targeted fluctuation range before 2022, the long-term JGB yield hovered near the upper limit of the range when the yield came under upward pressure due to interest rate developments in foreign financial markets. During this period, the 10-year swap rate (overnight index swap, OIS, rate) tended to diverge significantly from the 10-year JGB yield, far exceeding the 10-year JGB yield.

Chart 8: Long-term Yields and the Targeted Fluctuation Range under YCC



Note: Latest data are as of May 22, 2024. The broken line for the "Targeted fluctuation range under YCC" denotes the period from September 21, 2016, to July 31, 2018, when the targeted fluctuation range was not explicitly stated but perceived to be around ±0.1 percent, and the period from July 31, 2018, to March 19, 2021, when it was twice the size of the preceding period, i.e., around ±0.2 percent.

Source: Bloomberg.

How YCC works

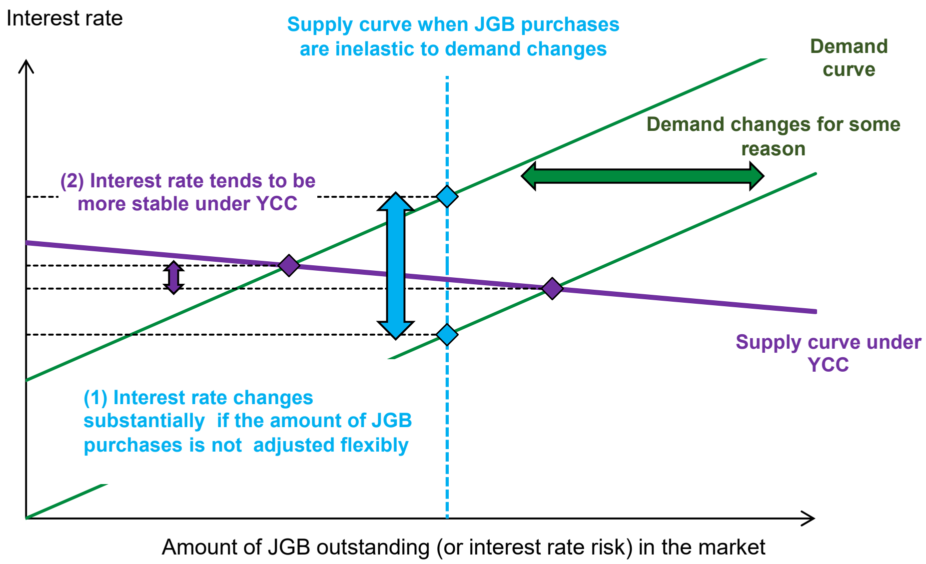
The YCC framework can be regarded as a type of government bond purchase program in that it affects the formation of interest rates in the market through large-scale JGB purchases. As such, the mechanisms through which it operates are the same as the QQE program that preceded it, and the considerations in the preceding section on the effect on long-term interest rates also apply to YCC.[15] On the other hand, QQE with YCC differs

[15] Employing the preferred-habitat model of Vayanos and Vila [2021], Lucca and Wright [2024] examine the effects of the Reserve Bank of Australia's Yield Target policy, which is not identical but similar to the BOJ's YCC. Based on the model, they classify the effects into (i) broad channels and (ii) narrow and super-narrow channels. Broad channels include the signaling effect, which is the effect on the yields of various

from QQE without YCC in that it guides long-term interest rates not through the purchase of JGBs based on a pre-announced plan, but by directly targeting the level of long-term JGB yields, which may affect the formation of long-term interest rates in a different manner than QQE without YCC.

In particular, under the previous QQE framework in which the amount of JGB purchases was scheduled, the fluctuations in JGB yields were greater, the greater the fluctuations in demand for government bonds. On the other hand, under the YCC framework, which targets the level of long-term JGB yields, the amount of purchases is determined endogenously in response to changes in the demand for government bonds, so that, in principle, fluctuations in interest rates should be smaller. Chart 9 illustrates this mechanism through a simple demand-supply curve analysis.

Chart 9. Effect of YCC on Interest Rate Volatility (Conceptual Illustration)



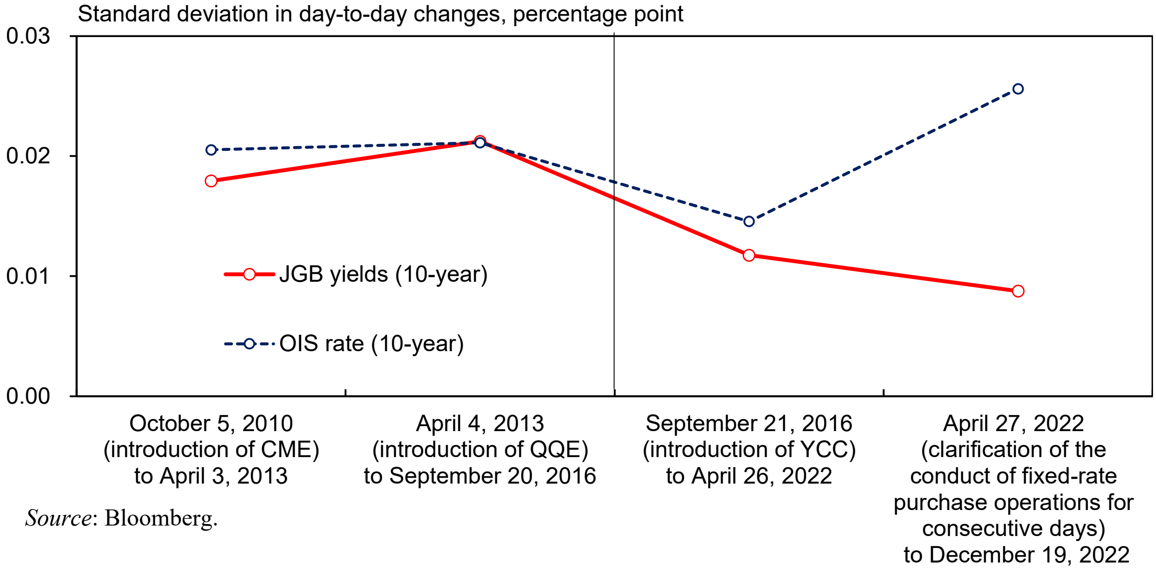
If the scheduled amount of JGB purchases is decided at each monetary policy meeting, as was the case with QQE before the introduction of YCC, the supply curve will be vertical because the amount of JGBs held by the rest of the market is fixed in the short run. In this case, if the demand for JGBs changes for some reason, that is, if the demand curve shifts, long-term yields will change significantly in response to the change in demand. On the other hand, under YCC, which targets the long-term JGB yield, the

assets (not limited to the purchased asset) through market participants' expectations about the future path of the short-term interest rate, and the portfolio-balance effect, which is the effect on the entire yield curve of government bonds through influencing the supply of interest rate risk in the market. Narrow and super-narrow channels include asset-specific liquidity effects, i.e., asset purchases affect the supply-demand balance of only the targeted assets or issues.

narrower or stricter the targeted fluctuation range is, the more horizontal the supply curve will be, restraining interest rate changes when the demand curve shifts. (Instead, the amount of JGB purchases will change substantially.) Moreover, if market participants sufficiently understand this mechanism of YCC, interest rate changes will be smaller even in the absence of actual JGB purchases. In other words, if market participants fully expect that interest rate changes will be suppressed, the mechanism may operate in advance by flattening the slope of the demand curve, thereby making interest rates less volatile.

While academic research on this kind of setup is still scarce, since the introduction of YCC, central banks in other countries have looked into the feasibility of adopting a similar policy framework, and a number of studies have empirically examined the impact of YCC.[16] First, with regard to the effects on the volatility of long-term interest rates, Hattori and Yoshida [2023], for example, use intraday trading data to empirically examine the effect of YCC on volatility and find that the stochastic nature of long-term interest rate movements changed after the introduction of YCC in that interest rates became stationary and less volatile. A similar observation applies when looking at the volatility in 10-year JGB yields since 2013, as seen in Chart 10. In terms of the real-world implications of this reduction in the volatility of market interest rates, it is likely that it reduced the uncertainty firms faced with regard to funding costs, which in turn likely had a positive impact on the real economy by making it easier for firms to formulate business plans.[17]

Chart 10. Historical Volatility of Long-term Interest Rates



Source: Bloomberg.

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[16] See, for example, the discussions in Federal Open Market Committee [2020] and Reserve Bank of Australia [2022]. While there are few cases of similar policies in the past, the Fed's yield curve targeting from 1942 to 1951 (at 2.5 percent for long-term bonds) is often cited as an example (Amamiya [2017] and Rose [2021]).

[17] According to the BOJ's March 2021 "Assessment for Further Effective and Sustainable Monetary Easing," low interest rate volatility may have a positive impact on business fixed investment (BOJ [2021]).

Second, some studies focus on the effectiveness of YCC. Specifically, they argue that if market participants sufficiently understand the YCC mechanism, it may be possible to control interest rates while reducing the amount of JGB purchases. For example, Bernanke [2016] and Higgins and Klitgaard [2020] suggest that using long-term interest rates as the direct target of operations means that a small amount of JGB purchases may have a sufficient effect to push down interest rates. Further, using a term structure model of interest rates that takes investors' preferred habitat into account, Koeda and Ueno [2022] show that as long as market participants have confidence in the long-term interest rate target of YCC, the long-term interest rate will remain close to the target even in the absence of actual JGB purchases, and that this effect occurs across the entire yield curve.

It should be noted, however, that whether this mechanism, which relies on market participants' expectations formation, works depends on the circumstances. This is illustrated by the study by Lucca and Wright [2024] examining the Reserve Bank of Australia's (RBA's) yield target policy for 3-year Australian government bonds conducted from 2020 to 2021. While they found that the policy had a stabilizing effect on interest rates when the policy was first introduced, once the inflation rate rose far above the RBA's forecasts after 2021 and the market lost confidence in the continuation of the yield target policy, arbitrage along the yield curve no longer worked sufficiently, so that government bond purchases no longer had the effect of pushing down yields on government bonds with maturities other than those subject to RBA purchases. Similarly, in Japan, the degree of market functioning deteriorated when from around mid-2022 to early 2023 long-term interest rates rose close to the upper bound of the targeted fluctuation range under YCC and arbitrage between the OIS rates and JGB yields as well as across different issues and maturities of JGBs became difficult, and such a deterioration in market functioning may have spread to other financial markets (see for example, Fukuma et al. [2024], Shiratsuka [2024], and Ochi and Osada [2023, 2024]).[18]

Finally, YCC may affect the effectiveness of other policy tools. For example, reviewing the RBA's experience in conducting its yield target policy, RBA [2022] argues that, in the early period after the introduction of yield targeting, the policy helped to reinforce the message that the RBA was committed to continued monetary easing, as it was highly consistent with the RBA's forward guidance at the time of keeping the policy rate unchanged at low levels for the time being.

Effects of setting a targeted fluctuation range under the YCC framework

Having discussed the possible effects of YCC on long-term interest rates from a theoretical perspective, we now outline our strategy for empirically quantifying the effect

[18] In response to this situation, the BOJ has implemented the Securities Lending Facility (SLF) in a flexible manner taking the degree of functioning of the JGB market into account, and, as noted above, since December 2022 has also increased flexibility in the conduct of YCC.

using a time series model.

In the construction of the empirical model, the choice of explanatory variables is key. In the case of quantifying the effect of JGB purchases, it is natural to expect that the relationship between the amount of JGB purchases or holdings and long-term interest rates is monotonic; that is, the larger the amount, the greater is the effect of pushing down interest rates. However, the effect of YCC differs depending on the situation, implying that the choice of the appropriate proxy variable to capture the effect is not straightforward. We therefore need to consider how YCC works in different situations. First, when market participants fully expect long-term interest rates to remain within the targeted range, long-term interest rates are likely to be formed based on the relationship between the BOJ's JGB holdings and the long-term yield, as shown in Chart 6. In this case, the effect of YCC is essentially the same as the effect of JGB purchases. On the other hand, in a situation in which the level of long-term interest rates is close to the upper or lower bound of the targeted range, or in which market participants increasingly expect that, in the absence of YCC, long-term interest rates would change beyond the targeted range in the future, the effect of YCC is likely to be enhanced by market participants' expectations that the BOJ will take measures to keep long-term interest rates within the targeted range through nimble responses. In fact, when interest rates came under upward pressure from 2022 onward, the BOJ implemented YCC in a strict manner so that long-term interest rates did not exceed the upper bound of the targeted range by conducting fixed-rate purchase operations for consecutive days, which kept long-term interest rates lower than they would have been in the absence of such a response. We can interpret this to mean that YCC works by influencing the shape of the demand and supply curves, as shown in Chart 9.[19,20]

Against this background, we construct indicators of the probability that the long-term yield will exceed the YCC range (for the upper and lower bounds, respectively) from market data, and then, using the empirical approach described in the following section, test the hypothesis that when the probability increases, the effect of YCC also increases. Specifically, we use option price data to calculate the probability that the long-term yield

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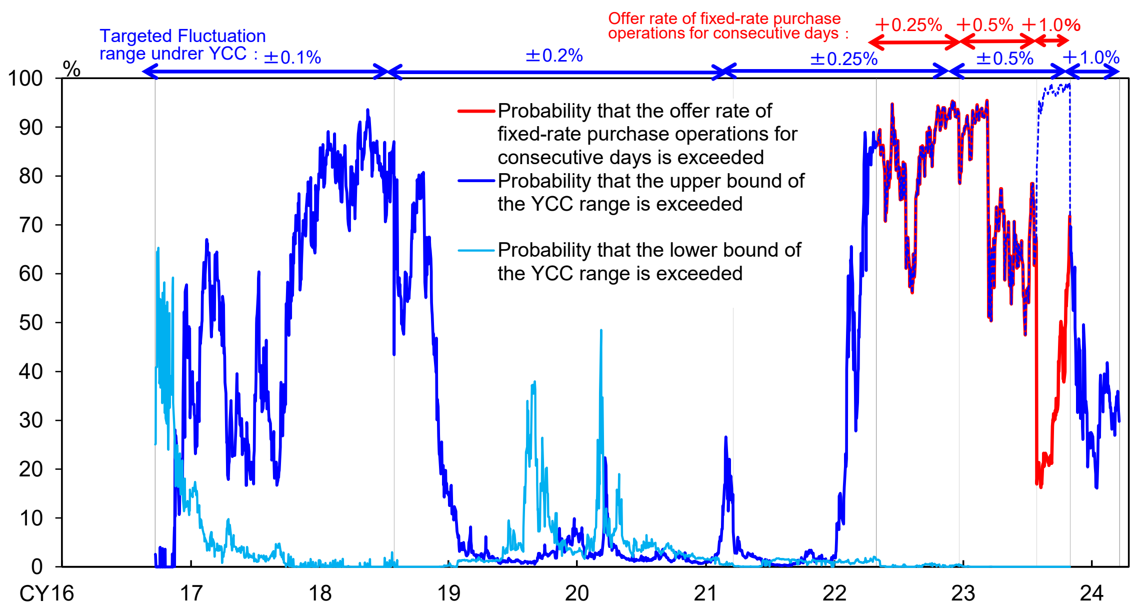
[19] This situation implies that market participants' confidence in YCC does matter. In this context, the structural model proposed by Koeda and Ueno [2022] suggests that the stricter the implementation of YCC, the greater is the effect of YCC through the flattening of the slope of the demand curve (where the slope of the demand curve represents the price semi-elasticity of the demand for government bonds by preferred-habitat investors). Such a structural model could be used, for example, to conduct a counterfactual analysis of the effect of increasing the degree of confidence in YCC. However, such an analysis is beyond the scope of this paper as it would require various additional assumptions.

[20] In addition, as noted earlier, the YCC framework, through the signaling effect, potentially also pushes down the expected short-term rate component of long-term interest rates in a way that reinforces forward guidance. Koeda and Wei [2023] find evidence of the signaling effect of YCC by conducting a counterfactual analysis using a term structure model of interest rates that incorporates macroeconomic variables.

in the market will exceed the YCC range in the next three months.[21] Chart 11 shows that, in the early period after the introduction of YCC, there was a considerable probability that the long-term yield might exceed the lower bound but not the upper bound of the YCC range (i.e., ±0.1 percent). Subsequently, the probability that the long-term yield might exceed the upper bound increased in 2018 due to speculation about a widening of the YCC range. From 2022, when the economy started to recover from the COVID pandemic and increases in foreign interest rates exerted upward pressure on Japanese long-term interest rates, the probability that the long-term yield might exceed the upper bound rose to over 90 percent in the second half of 2022. In Chart 11, the probability that the long-term yield might exceed the upper bound and the probability that it might exceed the offer rate for fixed-rate purchase operations for consecutive days are shown separately for the period from July to October 2023, as an upper bound for the YCC range of about 0.5 percent was used as reference, while the offer rate for fixed-rate purchase operations was set at 1.0 percent during this period.

Chart 11. Probability that the Long-term Yield Might Exceed the YCC Range in the Next Three Months



Note: Latest data are as of March 18, 2024. The part of the "Probability that the upper bound of the YCC range is exceeded" shown in a broken line represents the period during which the BOJ conducted fixed-rate purchase operations every business day. For details on the estimation, see Appendix B.
Sources: Bloomberg; LSEG Eikon.

[21] See Appendix B for details on how the data are constructed.

4. Empirical Results using Time Series Analysis

In this section, based on the discussion above, we construct time-series models of JGB purchases and YCC that are consistent with the theoretical considerations. Using various specifications, we quantitatively assess the effects of JGB purchases and YCC on long-term interest rates and the entire yield curve.

4.1. Effect of JGB Purchases and YCC on Long-term Interest Rates

Specifications with QE dummies

We start by providing an overview of the effects of past quantitative easing frameworks using specifications with simple dummy variables representing these frameworks as explanatory variables. Specifically, we employ ordinary least squares regression models with the following specification for long-term interest rates:

$$y_t^{10Y} = c + \alpha \cdot Controls_t + \beta \cdot QEdummies_t + \varepsilon_t,$$

where for the dependent variable (y_t^{10Y}) we use the 10-year JGB yield (i_t^{10Y}) and its two components: the expected short-term rate component (ES_t^{10Y}) and the term premium (TP_t^{10Y}), estimated using a term structure model of interest rates following previous studies. In addition, we use three variables to control for the major determinants of developments in long-term interest rates ($Controls_t$): the 10-year U.S. Treasury yield, the uncollateralized overnight call rate, and the inflation rate (year-on-year change in the consumer price index, excluding fresh food and energy and the effects of the consumption tax hikes).[22] In addition, we use five QE dummies for past QE frameworks ($QEdummies_t$): (i) the Quantitative Easing Policy (QEP) from March 2001 to February 2006, (ii) Comprehensive Monetary Easing (CME) from October 2010 to March 2013, (iii) Quantitative and Qualitative Monetary Easing (QQE) from April 2013 to December 2015, (iv) QQE with the Negative Interest Rate Policy (NIRP) from January 2016 to August 2016, and (v) QQE with Yield Curve Control (YCC) from September 2016 to March 2024, where the variables take 1 for the corresponding period (and 0 for other periods).

Chart 12 shows the estimation results. In Model 1, where the dependent variable is the 10-year JGB yield, the coefficients on all QE dummies are negative, indicating that the various QE policies tended to lower the long-term interest rate. In particular, the effect is large and significant in the periods after the introduction of QQE. Next, when we split the dependent variable into the expected short-term rate component and the term premium

[22] While there are various other variables that we could include as determinants of long-term interest rates, in our analysis we focus on these three variables, which are often cited as the primary drivers of short-term movements in 10-year interest rates in practice. The adjusted R-squared of the model using only these three variables is around 0.85, indicating that these three variables have high explanatory power.

(Models 2 and 3), the results are generally similar to those of Model 1; that said, while the coefficients on the QEP and CME dummies are significant in the estimation for the expected short-term rate component, they are not in that for the term premium. This may reflect the fact that JGB purchases in these periods were targeted at issues with relatively short remaining maturities; it is also consistent with the results of previous studies suggesting that JGB purchases affect yields mainly through the signaling effect (e.g., Ugai [2007] and Oda and Ueda [2007]). Similar results are obtained in the estimations using data for the period up to March 2013 before the introduction of QQE (Models 4 to 6).

Chart 12. Estimation Results: Specifications with QE Dummies

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	10-year yield	10-year expected short-term rate component	10-year term premium	10-year yield	10-year expected short-term rate component	10-year term premium
Constant	0.558 ***	0.587 ***	-0.018	0.495 ***	0.733 ***	-0.232
10-year U.S. Treasury yields	0.203 ***	0.061 ***	0.151 ***	0.230 ***	0.023	0.220 ***
Uncollateralized overnight call rate	0.485 **	0.576 ***	-0.121	0.271	0.694 ***	-0.514 **
CPI (less fresh food and energy)	0.014	0.082 ***	-0.067 ***	0.089 ***	0.025	0.091
Time dummy :						
QEP	-0.151 **	-0.159 ***	0.011	-0.164 **	-0.168 ***	0.005
CME	-0.094	-0.181 ***	0.097	-0.022	-0.288 ***	0.292 **
QQE	-0.569 ***	-0.325 ***	-0.260 **	—	—	—
NIRP	-1.010 ***	-0.708 ***	-0.328 *	—	—	—
YCC	-0.907 ***	-0.410 ***	-0.529 ***	—	—	—
Adjusted R-squared	0.931	0.827	0.798	0.746	0.747	0.482
AIC	-0.526	-1.032	-0.209	-0.319	-1.126	-0.086
Estimation Period	January 1997 to March 2024			January 1997 to March 2013		

Note: ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg.

Stock and flow effects of JGB purchases

These results indicate that the BOJ's JGB purchases have had a substantial effect since the introduction of QQE, when the large-scale purchases began. To examine whether the effect of JGB purchases is caused by stock or flow effects, we next conduct estimations using the following specification in which JGB holdings and the amount of JGB purchases are used as explanatory variables instead of the QE dummies for each period:

$$y_t^{10Y} = c + \alpha \cdot Controls_t + \gamma_1 \cdot JGBstock_t + \gamma_2 \cdot JGBflow_t + \varepsilon_t.$$

We start by checking for the existence of stock effects. To this end, based on the discussion in Section 2, we include three relevant variables in the specification as indicators of the BOJ's JGB holdings ($JGBstock_t$): (A) the share of the BOJ's JGB holdings in the total amount of JGBs outstanding, (B) the risk-adjusted share of the BOJ's JGB holdings in the total amount of JGBs outstanding (10-year bond equivalent), and (C) the expected future share of the BOJ's JGB holdings (adjusted for interest rate risk, 10-year bond equivalent).[23, 24]

Chart 13. Estimation Results: Stock Effect of JGB Purchases

		(1)	(2)	(3)	(4)	(5)
	Dependent variable	10-year yield				
	Constant	-0.307 ***	0.390 ***	0.310 ***	0.522 ***	0.480 ***
	10-year U.S. Treasury yields	0.329 ***	0.255 ***	0.270 ***	0.229 ***	0.240 ***
	Uncollateralized overnight call rate	1.329 ***	0.697 ***	0.759 ***	0.738 ***	0.719 ***
	CPI (less fresh food and energy)	-0.152 ***	-0.002	-0.019	0.020	0.013
A	Share of BOJ's JGB holdings in total		-0.018 ***			-0.025 ***
B	Risk adjusted share of BOJ's JGB holdings in total			-0.022 ***		
C	Expected 2-year ahead share of BOJ's JGBs holdings in total (adjusting for interest rate risk)				-0.024 ***	
B-A	Difference between the actual shares when adjusting and not adjusting for interest rate risk					-0.026 **
C-B	Expectation of future changes in JGB holdings					-0.016 ***
	Adjusted R-squared	0.847	0.918	0.926	0.933	0.935
	AIC	0.259	-0.364	-0.465	-0.567	-0.596
	Estimation Period	January 1997 to March 2024				

Note: ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg.

Chart 13 presents the estimation results. While the coefficients on the indicators of the BOJ's JGB holdings are statistically significant in Models 2 to 4, the estimated

[23] We perform unit root tests on the stock indicators and find that the null hypotheses that each indicator is a non-stationary process are not rejected. Therefore, we additionally conduct cointegration tests to confirm that the models are not spurious regressions and find that the null hypothesis of no cointegration is rejected for each model (in Chart 13) at the 5 percent confidence level.

[24] While many previous studies use JGB holdings in the rest of the market relative to nominal GDP, the ratio we employ uses the total JGBs outstanding as the denominator; i.e., we calculate the share of the BOJ's JGB holdings as (1 - JGB holdings in the rest of the market) ÷ total JGBs outstanding. The reason is that, given that the amount of JGBs outstanding has continued to increase, the former is more likely to have a trend than the latter, which is calculated as a share. Nakamura and Yagi [2017] note that panel data for 23 OECD countries do not show a simple relationship between total outstanding government debt and long-term interest rates, and that empirical analyses should take market participants' expectations of future fiscal consolidation into account. Meanwhile, Ichiue and Shimizu [2012] argue that it is important to consider the financial assets held by the government and the share of government debt held by foreign investors.

coefficients are larger when the amount of risk is taken into account (Model 3) and when future expectations are also taken into account (Model 4), and the fits of the models (in terms of the adjusted R-squared) are also higher when they are taken into account. To examine whether the amount of risk and future expectations, which are considered important for understanding the stock effect, contain additional information, we additionally estimate Model 5, which decomposes the expected future share of the BOJ's JGB holdings (C) into the actual share of the BOJ's JGB holdings without adjusting for interest rate risk (A), the difference between the actual shares when adjusting and not adjusting for interest rate risk (B-A), and expectations of future changes in the BOJ's JGB holdings (C-B). We find that each of these plays a significant role in lowering interest rates. In fact, at the time of the introduction of QQE, the BOJ announced that it would double its holdings of long-term JGBs over the next two years, and market participants appear to have formed expectations incorporating this policy announcement relatively quickly. Thus, Models 4 and 5, which take such future expectations into account, are likely to provide more accurate results in terms of the timing of the stock effect. This suggests that considering the announcement effect is key in the results.

Next, we check for the existence of the flow effect. To do so, we consider the monthly change in the BOJ's JGB holdings (seasonally adjusted), which indicates the net flow of JGB purchases (i.e., taking redemptions of JGB holdings into account), as an indicator of the BOJ's JGB purchases ($JGBflow_t$), and add it to Model 4 in Chart 13.[25]

Chart 14 shows the estimation results. In Model 1, the coefficient on the stock indicator, the expected future share of BOJ holdings, is similar in magnitude and statistical significance to the results in Chart 13, while we do not obtain a significant coefficient estimate for the flow indicator, the monthly change in JGB holdings. Moreover, the coefficient has the wrong sign. We obtain the same result in Model 2, where the estimation period is different, while in Model 3, which uses data from before the introduction of QQE, the coefficient is negative but not significant. That said, in Model 4, when the dependent variable is split into the expected short-term rate component and the term premium, the monthly change in JGB holdings has a significant negative effect in the specification using the expected short-term rate component, while the coefficient has the wrong sign in the specification using the term premium. This suggests that information on the actual pace of purchases may affect long-term interest rates through the signaling effect, i.e., through influencing market participants' expectations about the policy stance for the future path of short-term interest rates. This tendency is also observed in Model 5, in which the expected future share of BOJ holdings is decomposed

[25] Another potential indicator of BOJ JGB purchases is the gross flow of JGB purchases. We therefore conducted a robustness check using the amount of purchases of JGBs with a remaining maturity of 9 to 10 years (excluding purchases through fixed-rate purchase operations) as a ratio to new JGB issuance, which is obtained using issue-specific data. However, the results were insignificant and in some of the specifications the estimated coefficient had the wrong sign.

(C) into the actual share of BOJ holdings taking interest rate risk into account (B) and expectations of future changes in JGB holdings (C-B). Meanwhile, expectations of future changes in JGB holdings contain both flow and stock information in the sense that they are based on the assumption that the current pace of purchases will continue. That said, the effect of such expectations on the term premium is significantly negative, while the coefficient on the expected short-term rate component has the wrong signs. This result suggests that expectations regarding future JGB purchases affect long-term interest rates through the portfolio-balance effect.

Chart 14. Estimation Results: Flow Effect of JGB Purchases

Dependent variable	(1)	(2)	(3)	(4)			(5)		
	10-year yield			10-year yield (sum of estimated coefficients)	10-year expected short-term rate component	10-year term premium	10-year yield (sum of estimated coefficients)	10-year expected short-term rate component	10-year term premium
Constant	0.515 ***	0.500 ***	0.590 ***	*0.525*	0.478 ***	0.047	*0.513*	0.468 ***	0.046
10-year U.S. Treasury yields	0.234 ***	0.240 ***	0.252 ***	*0.242*	0.077 ***	0.165 ***	*0.245*	0.080 ***	0.165 ***
Uncollateralized overnight call rate	0.695 ***	0.591 ***	0.521 ***	*0.689*	0.797 ***	-0.108	*0.698*	0.805 ***	-0.107
CPI (less fresh food and energy)	0.029 *	0.060	0.092 **	*0.021*	0.088 ***	-0.067 ***	*0.010*	0.079 ***	-0.068 **
Expected 2-year ahead share of BOJ's JGBs holdings in total (adjusting for interest rate risk)	-0.024 ***	-0.023 ***	-0.039 *	*-0.025*	-0.009 ***	-0.016 ***			
Risk adjusted share of BOJ's JGB holdings in total							*-0.025*	-0.009 ***	-0.016 ***
Expectation of future changes in JGB holdings							*-0.012*	0.002	-0.014 *
Monthly change in JGB holdings	0.067	-0.003	-0.059	*0.075*	-0.074 **	0.149 ***	*-0.116*	-0.237 ***	0.122
Adjusted R-squared	0.935	0.878	0.749	—	0.826	0.778	—	0.833	0.777
AIC	-0.583	-0.433	-0.332	—	-1.030	-0.122	—	-1.072	-0.117
Estimation Period	January 1997 to March 2024	January 1997 to August 2016	January 1997 to March 2013	January 1997 to March 2024			January 1997 to March 2024		

Note: ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg.

Effect of setting the targeted fluctuation range under the YCC framework

Next, we quantitatively analyze the effect of setting the targeted fluctuation range under YCC on long-term interest rates. Specifically, as noted above, we examine the hypothesis that the effect of YCC increases as the probability of long-term interest rates exceeding the upper (or lower) bound of the YCC range increases. To do so, we use the following specification, which includes the probability that long-term interest rates might exceed the upper (or lower) bound of the YCC range as an explanatory variable:

$$TP_t^{10Y} = c + \alpha \cdot Controls_t + \gamma_1 \cdot JGBstock_t + \gamma_2 \cdot JGBflow_t + \delta \cdot YCCeffects_t + \varepsilon_t$$

In the specification, we use the term premium as the dependent variable, since the effect of setting the YCC range is not expected to affect the expected short-term rate component, and add an explanatory variable that captures the effect of YCC ($YCCeffects_t$) to the term premium model in Chart 14. Specifically, we use the monthly amount of fixed-rate purchase operations (as a percentage of monthly new JGB issuance, hereafter referred to as the fixed-rate purchase operations share), which can also be regarded as a flow variable, and the probability that the targeted long-term yield exceeds the upper (or lower) bound of the YCC range, which is priced into the options market, as discussed in Section 3. [26] As these probabilities increase, market participants' expectations that the likelihood of a response by the BOJ to prevent interest rates from rising (or falling) in the future increases are factored into market prices in advance. In addition, since the effect of YCC is likely to have further strengthened after the BOJ's clarification in April 2022 of how it will conduct fixed-rate purchase operations for consecutive days, we also use a specification that includes the probability that the long-term yield might exceed the offer rate of fixed-rate purchase operations for consecutive days as an explanatory variable. As for the expected future share of BOJ holdings, we use two specifications shown in Chart 14.

The estimation results, presented in Chart 15, show that the coefficients on both the fixed-rate purchase operations share and the probability that the upper (or lower) bound of the YCC range might be exceeded are significant and have the right sign in all models.[27] The coefficients on the probability that the long-term yield might exceed the offer rate of fixed-rate purchase operations for consecutive days are also significant and somewhat larger than those on the probability that the long-term yield might exceed the upper bound of the YCC range, indicating that the fixed-rate purchase operations have a stronger effect. In fact, in periods of upward pressure on Japanese long-term interest rates after the introduction of YCC, the expected short-term rate component increased due to heightened expectations of future monetary tightening (Charts 2 and 11). In response to this, the BOJ undertook measures such as fixed-rate purchase operations, which had the

[26] In our regressions, we use the logit transformation of the probabilities that the long-term yield exceeds the upper or lower bound of the YCC range (or the offer rate of fixed-rate purchase operations for consecutive days).

[27] Due to possible reverse causality, our regression may suffer from endogeneity. When the term premium rises for some reason, this may increase the probability that the long-term yield as a whole exceeds the upper bound of the YCC range (and/or the offer rate of "fixed-rate purchase operations for consecutive days") and therefore also increase the fixed-rate purchase operations share as the BOJ conducts measures such as fixed-rate purchases operations. This may result in an underestimation of the negative coefficients on these explanatory variables (in absolute value). That said, since the upward pressure on interest rates during periods when the probabilities actually increased was mainly due to the rise in foreign interest rates and the rise in inflation in Japan, it seems reasonable to regard the probability as an exogenous variable in our estimation.

effect of pushing down the term premium.

Chart 15. Estimation Results: Effects of YCC on the Term Premium

	(1)	(2)	(3)	(4)
Dependent variable	10-year term premium			
Constant	0.000	0.005	0.016	0.024
10-year U.S. Treasury yields	0.177 ***	0.174 ***	0.176 ***	0.172 ***
Uncollateralized overnight call rate	-0.298	-0.301	-0.315	-0.320
CPI (less fresh food and energy)	-0.008	-0.007	0.001	0.004
Expected 2-year ahead share of BOJ's JGBs holdings in total (adjusting for interest rate risk)	-0.011 ***		-0.011 ***	
Risk adjusted share of BOJ's JGB holdings in total		-0.009 **		-0.010 **
Expectation of future changes in JGB holdings		-0.016 ***		-0.018 ***
Monthly change in JGB holdings	-0.007	0.062	-0.005	0.076
Ratio of fixed-rate purchase operations to JGB issuance	-0.004 ***	-0.004 ***	-0.002 **	-0.002 **
Probability that the upper bound of the YCC range is exceeded (from Sep. 2016 to Mar. 2024)	-0.048 ***	-0.050 ***		
Probability that the upper bound of the YCC range is exceeded (from Sep. 2016 to Apr. 2022, from Nov. 2023 to Mar. 2024)			-0.045 ***	-0.047 ***
Probability that the offer rate of fixed-rate purchase operations for consecutive days is exceeded (from May. 2022 to Oct. 2023)			-0.059 ***	-0.062 ***
Probability that the lower bound of the YCC range is exceeded	0.033 ***	0.027 ***	0.033 ***	0.025 **
Adjusted R-squared	0.818	0.818	0.819	0.820
AIC	-0.312	-0.311	-0.318	-0.319
Estimation Period	January 1997 to March 2024			

Note: ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg; LSEG Eikon.

Quantitative assessment of the effect of JGB purchases

Finally, based on the results of the above estimations, we quantitatively assess the effect of large-scale JGB purchases on long-term interest rates from two perspectives: the effect of the amount of JGB purchases (flow and stock effects) and the effect of setting the YCC range. Specifically, these effects are quantified using five models based on the following three approaches. The first approach is to quantify the effect of YCC as the difference between actual developments in the long-term yield and the counterfactual evolution of the long-term yield in the absence of YCC, using estimation results based on data for the period prior to the introduction of YCC and assuming that the coefficients in the model remained unchanged. The results based on this approach are shown as Model 1 in Chart 16. The second approach is to quantify the effect using a full model in which the dependent variable is the 10-year yield and the explanatory variables include both the effect of JGB purchases and the effect of YCC (Models 2 and 4 in Chart 16). The last approach is similar to the second approach, but the model is estimated separately for the expected short-term rate component and the term premium, and the estimated coefficients are then summed (Models 3 and 5 in Chart 16).[28]

Chart 16. Estimation Results: Final Models

	(1)	(2)	(3)			(4)	(5)		
Dependent variable	10-year yield	10-year yield	10-year yield (sum of estimated coefficients)	10-year expected short-term rate component	10-year term premium	10-year yield	10-year yield (sum of estimated coefficients)	10-year expected short-term rate component	10-year term premium
Constant	0.499 ***	0.524 ***	*0.475*	0.465 ***	0.010	0.512 ***	*0.495*	0.476 ***	0.019
10-year U.S. Treasury yields	0.241 ***	0.232 ***	*0.247*	0.082 ***	0.165 ***	0.238 ***	*0.238*	0.078 ***	0.159 ***
Uncollateralized overnight call rate	0.590 ***	0.634 ***	*0.776*	0.776 ***		0.645 ***	*0.798*	0.798 ***	
CPI (less fresh food and energy)	0.060 ***	0.050 ***	*0.090*	0.090 ***		0.045 ***	*0.082*	0.082 ***	
Expected 2-year ahead share of BOJ's JGBs holdings in total (adjusting for interest rate risk)	-0.023 ***	-0.022 ***	*-0.020*	-0.010 ***	-0.011 ***				
Risk adjusted share of BOJ's JGB holdings in total						-0.024 ***	*-0.018*	-0.009 ***	-0.009 **
Expectation of future changes in JGB holdings						-0.012 ***	*-0.014*		-0.014 ***
Monthly change in JGB holdings						-0.141 **	*-0.208*	-0.208 ***	
Ratio of fixed-rate purchase operations to JGB issuance	—	-0.001	*-0.002*		-0.002 *	0.000	*-0.002*		-0.002 **
Probability that the upper bound of the YCC range is exceeded (from Sep. 2016 to Apr. 2022, from Nov. 2023 to Mar. 2024)	—	-0.009 ***	*-0.042*		-0.042 ***	-0.007 *	*-0.046*		-0.046 ***
Probability that the offer rate of fixed-rate purchase operations for consecutive days is exceeded (from May. 2022 to Oct. 2023)	—	-0.025 ***	*-0.054*		-0.054 ***	-0.021 ***	*-0.059*		-0.059 ***
Probability that the lower bound of the YCC range is exceeded	—	-0.003	*0.032*		0.032 ***	0.009	*0.025*		0.025 **
Adjusted R-squared	0.878	0.937	—	0.824	0.813	0.938	—	0.833	0.813
AIC	-0.441	-0.609	—	-1.022	-0.291	-0.621	—	-1.077	-0.290
Estimation Period	January 1997 to August 2016	January 1997 to March 2024							

Note: ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg; LSEG Eikon.

Chart 16 presents the estimation results of the final models. Starting with the control variables, we find that the coefficients on the 10-year U.S. Treasury yield are stable at around 0.25 in all models. The coefficients on the uncollateralized overnight call

[28] To improve the accuracy and interpretability of the quantitative results, we exclude explanatory variables that have the wrong sign.

rate range from 0.5 to 0.8, depending on whether we use the 10-year yield or the expected short-term rate component as the dependent variable. Similarly, the coefficients on the inflation rate range from 0.04 to 0.09, but we can ignore the difference as the coefficients are quite small relative to those on the other control variables.

Turning to the coefficients on the stock variables of JGB purchases, in particular the share of BOJ holdings and the expected future share of BOJ holdings, these are generally stable at around -0.02 in all models. On the other hand, expectations of future changes in JGB holdings over the next two years have an effect only on the term premium, and the coefficients on this variable are smaller than those on the share of BOJ holdings. Next, looking at the coefficients on the flow variables of JGB purchases, Models 4 and 5, which include the monthly change in JGB holdings as an additional explanatory variable, show that JGB purchases had an effect on the expected short-term rate component, which contrasts with expected future changes in JGB holdings, which did not have an effect. Moreover, the coefficients are fairly large at around -0.1 to -0.2. Finally, regarding the effect of YCC, Models 2 to 5 find that the fixed-rate purchase operations share has the effect of pushing down interest rates, although the coefficients are small. Meanwhile, the probability that the long-term yield might exceed the upper (or lower) bound of the YCC range had a significant effect on the long-term yield, mainly through the effect on the term premium. The same is true for the probability that the long-term yield might exceed the offer rate of fixed-rate purchase operations for consecutive days, and the coefficient is somewhat larger than that for the probability that the upper bound might be exceeded.

Chart 17 presents developments over time in the effect of JGB purchases and the effect of the YCC range based on the coefficients obtained in Models 1 to 5. The chart shows the following. First, the magnitude of and developments in the effect of JGB purchases are generally similar across all models since the coefficients on the share of BOJ holdings are roughly similar. Since the introduction of QQE in 2013, JGB purchases have pushed down long-term interest rates significantly, with the reduction following the introduction of YCC in 2016 reaching about 1 percent in all models. On the other hand, while the effect of the YCC range varies somewhat from model to model, it gradually strengthened from the introduction of YCC in 2016 to 2018 and temporarily declined in 2022. Subsequently, it had a large effect in restraining long-term interest rates when upward pressure on interest rates increased from 2022 onward. On the other hand, the diffusion index for the degree of JGB market functioning in the Bond Market Survey deteriorated substantially during this period, suggesting that as the effect of YCC strengthened, this had a negative impact on the price discovery function of the market and liquidity.[29]

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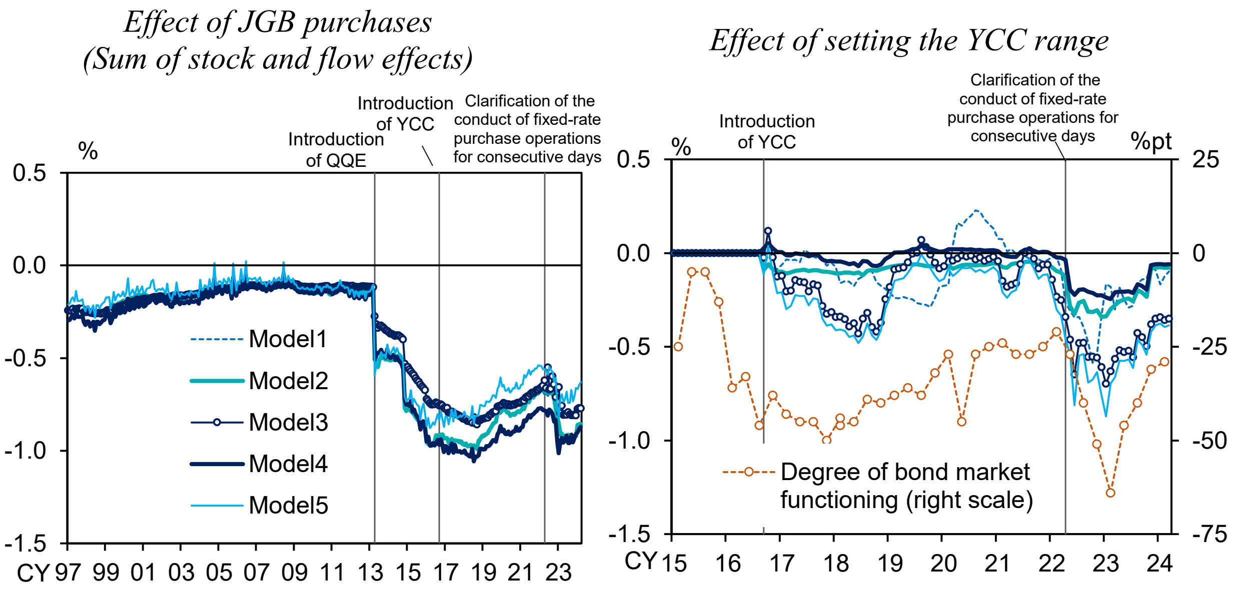
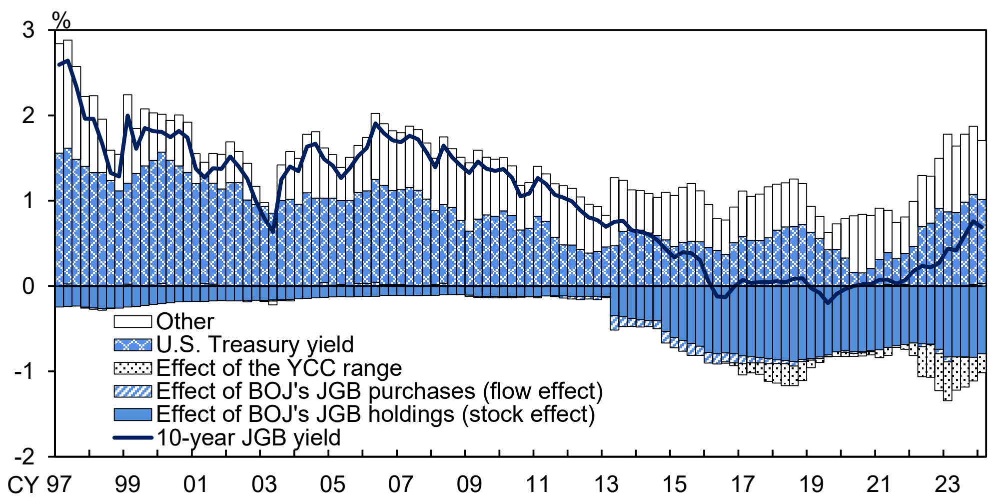
[29] Studies examining the effect of large-scale JGB purchases on market functioning and liquidity in detail include Fukuma et al. [2024]. Meanwhile, Ochi and Osada [2024] examine how the functioning of corporate bond markets works as a transmission channel between the large-scale bond purchases and the real economy.

Chart 17. Effects of JGB Purchases and YCC Based on the Final Models



Note: Based on the estimation results for each model in Chart 16.
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg; LSEG Eikon.

Chart 18. Sources of Changes in the Long-term JGB Yield
(Average of Models 4 and 5)



Note: Figures are calculated based on the average of the coefficients obtained in Models 4 and 5 in Chart 16.
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg; LSEG Eikon.

In addition, to separately assess the flow and stock effects of JGB purchases, we decompose changes in the long-term yield using the results of Models 4 and 5, which take the signaling effect of the flow of JGB purchases into account. The results are shown in Chart 18.[30] For the calculation, we use the simple average of the results obtained from

[30] The results in the April 2024 issue of the BOJ's *Outlook Report* (Charts B6-4 and B6-5 in Box 6, "Impact of the BOJ's JGB Purchases on the Yield Curve") correspond to the results of Models 2 and 3 in Chart 16.

each model. The results show that (i) the stock effect of JGB purchases gradually strengthened after the introduction of QQE and has generally been at around 1 percent since the introduction of YCC, and (ii) the YCC range restrained the long-term yield when there was upward pressure on Japanese long-term interest rates. In addition, (iii) the flow effect of JGB purchases, unlike the stock effect, had the effect of pushing down the expected short-term rate component, particularly during the period when the BOJ increased JGB purchases after the introduction of QQE.

4.2. Effect of JGB Purchases and YCC on the Entire Yield Curve

Finally, by extending the above analytical framework to JGBs of different maturities, we quantify the effect of JGB purchases and the YCC framework on the entire yield curve. Specifically, we estimate Model 5 in Chart 16 using maturities ranging from 1 to 9 years for the expected short-term rate component, the term premium, and U.S. Treasury yields. Charts 19 and 20 show the coefficients and their standard deviations for the main explanatory variables (see Appendix C for detailed estimation results).

Starting with the effect of JGB purchases, Chart 19 shows that the impact of both the flow (monthly changes in JGB holdings) and the stock (the share of the BOJ's JGB holdings in total JGBs) on the expected short-term rate component tends to be larger for long maturities. However, the incremental increase for longer maturities gradually diminishes, implying that expected short-term interest rates are pushed down mainly over the medium term. On the other hand, while the impact of the expected future share of BOJ holdings on the term premium also tends to be larger for longer maturities, the impact appears to be particularly large for maturities of more than 5 years, indicating that the stock effect mainly impacts longer maturities. These results are in line with the theoretical predictions of preferred-habitat models such as the one proposed by Koeda and Ueno [2022].

Turning to the effects of YCC, which are shown in Chart 20, the estimation results indicate that fixed-rate purchase operations had an effect on the term premium only for 10-year JGBs, i.e., JGBs that were subject to BOJ purchases. In fact, such an effect on interest rates was observed only for new issues, which were subject to the fixed-rate purchase operations, so that spreads between new issues (on-the-run issues) and existing issues of similar maturity (off-the-run issues) widened. These findings indicate that the estimated effect of the fixed-rate purchase operations corresponds to the asset-specific liquidity effect (super-narrow channel) discussed by Lucca and Wright [2024].[31] On the other hand, the results also show that the probability that the upper bound of the YCC range is exceeded has an effect on the term premium across a wide range of the yield

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In order to conduct a more detailed analysis of the flow and stock effect, we here focus on Models 4 and 5, which are extension of those models, and use Models 2 and 3 as benchmarks.

[31] Similarly, Koeda and Wei [2024], employing panel data estimation using issue-specific data, find that the conduct of fixed-rate purchase operations affected only the yields of specific JGB issues.

curve, including not only 10-year yields but also medium-term yields. Finally, we find that the effect of the probability that the offer rate of fixed-rate purchase operations for consecutive days is exceeded is even larger, and that the effect of the probability that the lower bound of the YCC range is exceeded is symmetrical to the corresponding results for the upper bound.

Chart 19. Estimation Results, by Maturity: Effects of JGB Purchases (Flow and Stock Effects)

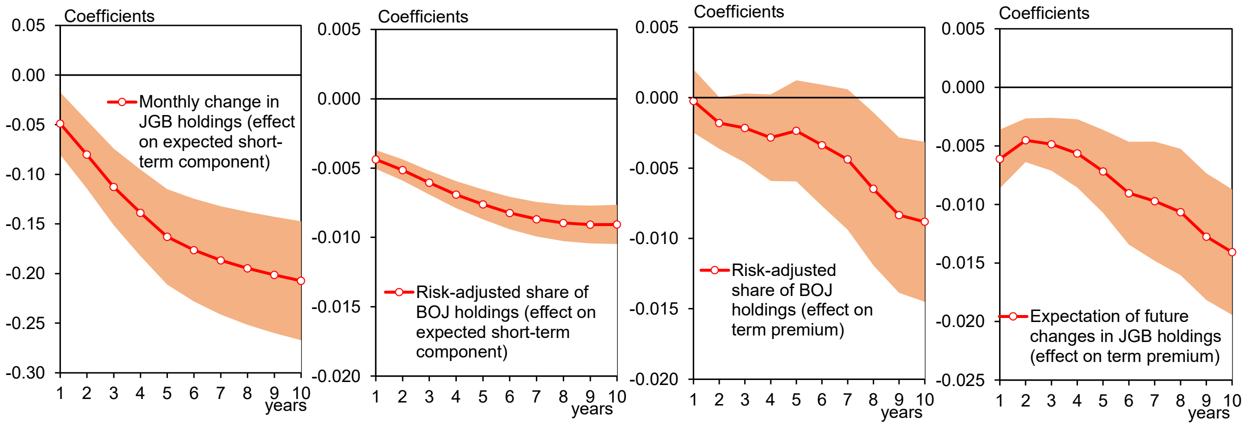
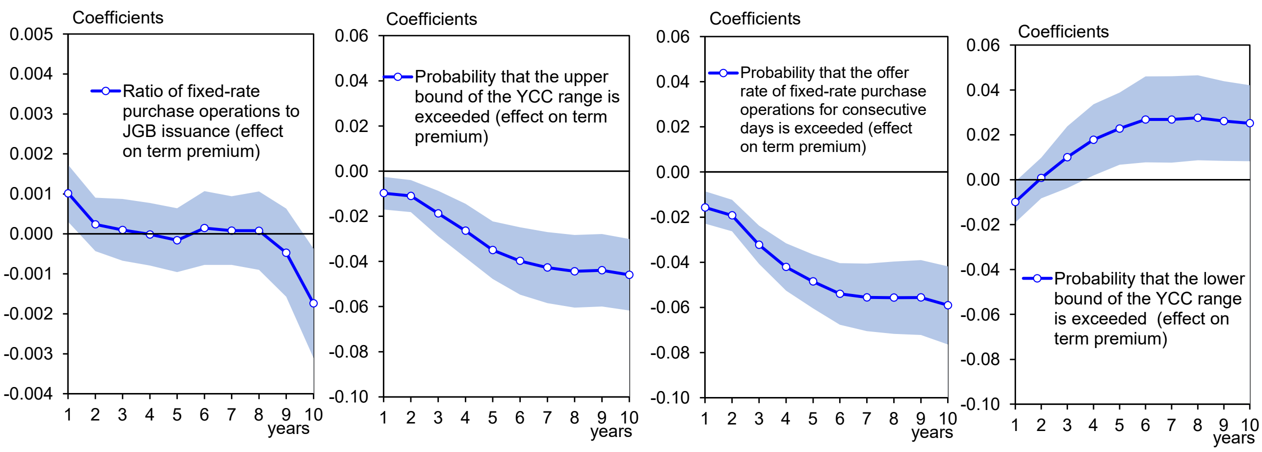


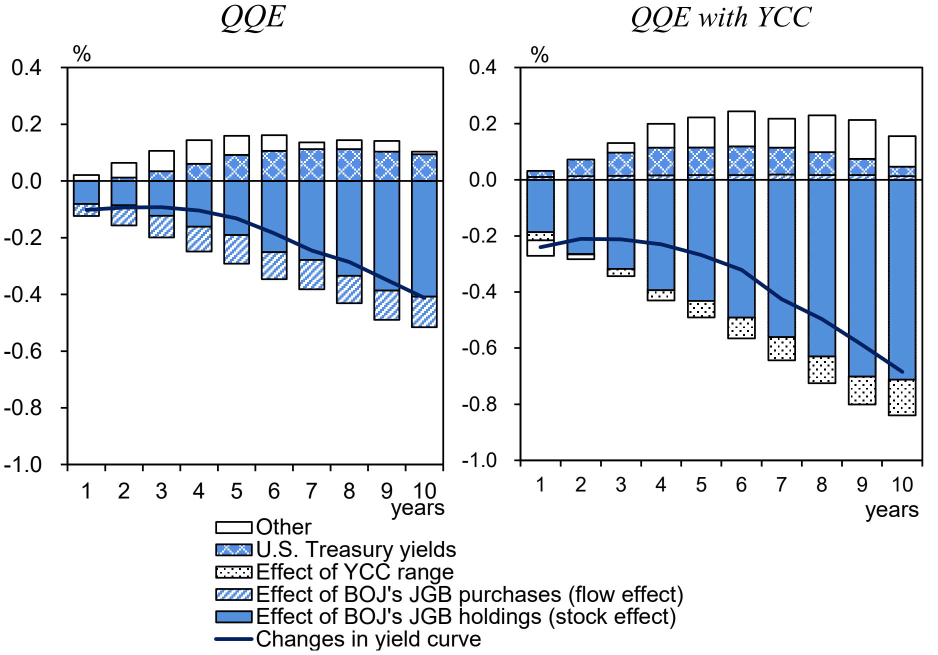
Chart 20. Estimation Results, by Maturity: Effects of YCC



Note: The shaded areas in Charts 19 and 20 denote the 90 percent confidence intervals.
Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg; LSEG Eikon.

Finally, we decompose changes in the entire yield curve following the introduction of QQE into the contribution of different sources of change. Specifically, we additionally estimate Models 4 and 5 in Chart 16 for maturities ranging from 1 year to 9 years and sum the coefficients of these two models for each maturity. The results are presented in Chart 21 and indicate that the large-scale monetary easing under QQE and YCC pushed down not only the 10-year yield but also yields for a wide range of maturities (i.e., the entire yield curve), and that the main channel was the stock effect.

Chart 21. Sources of Changes in the Entire Yield Curve



Notes: 1. In the left-hand panel, figures are the average from April 2013 to August 2016 relative to the average from January 2012 to March 2013. In the right-hand panels, figures are the average from September 2016 to March 2024 relative to the average from January 2012 to March 2013.
2. Figures are calculated based on the average coefficients of Models 4 and 5 in Chart 16 for each maturity from 1 year to 10 years. In the estimations, U.S. Treasury yields for the corresponding maturities are used.

Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg; LSEG Eikon.

5. Conclusion

This paper presented an empirical analysis of the effect of the BOJ's JGB purchases on long-term interest rates in Japan, taking academic developments on central bank purchases of government bonds into account. The main results can be summarized in the following three points. First, having quantified the effect of JGB purchases taking market participants' expectations about the future path of such purchases into account, we find that the effect of JGB purchases on interest rates has been driven by the increase in JGB holdings (i.e., the stock effect), which affects market participants' risk allocation. In contrast, the effect of the daily conduct of JGB purchases (i.e., the flow effect), which affects the supply and demand in the secondary market and market expectations about the future stance of monetary policy, appears to have been relatively modest. Second, with regard to the YCC framework introduced in September 2016, in addition to the flow and stock effects described above, we find that it had the effect of restraining interest rate increases when the long-term yield approached the upper bound of the YCC range. This effect tended to be larger when the BOJ took countermeasures and market participants expected such countermeasures. Third, our analysis of interest rates at different maturities suggested that government bond purchases and YCC had an effect on interest rates across the entire yield curve.

The aim of this paper was to present a tractable time series model that is consistent with theory and previous research results, and to obtain quantitative results that are as robust as possible. That said, such a time series model is a non-structural reduced-form model without any assumptions about the economic structure, and it is necessary to be aware of so-called model risks, such as the risk that the proxy variables we use for stock and flow effects are not always representative or that the estimation results may be biased due to omitted variables.[32] In particular, sensitivities in the model may vary over time, and the model may not be able to accurately capture changes in market expectations if they change dramatically.[33,34] This means that the results presented here should be interpreted with considerable caution. On the other hand, since our model is relatively simple and easy to understand, it is useful in practice for quantitatively assessing the effects of policy measures on the entire yield curve from time to time. Moreover, while we incorporate new ideas based on developments in recent academic research, our results are similar to those in the BOJ's September 2016 "Comprehensive Assessment" and the March 2021 "Assessment for Further Effective and Sustainable Monetary Easing," in which the BOJ attempted to quantity the effects of its quantitative easing policies using time series models. Thus, our finding that the BOJ's large-scale JGB purchases under QQE and YCC have pushed down the entire yield curve are likely to be relatively robust.

In March 2024, the BOJ decided that its large-scale monetary easing under the QQE with YCC framework had fulfilled its role, and decided to shift to a monetary policy framework that uses short-term interest rates as the primary policy tool.[35] Under this framework, long-term interest rates are essentially formed in financial markets, and the effect of the targeted range on long-term interest rates presented in Chart 18 is likely to

[32] While there are many studies that use sophisticated methods to identify monetary policy shocks, they may, as highlighted by Bernanke [2020], be subject to model risk or their shock identification strategies may not detect macroeconomic effects well. In practice, it would be useful to examine the advantages and disadvantages of different approaches, including the one employed in this paper.

[33] In times of higher interest rate volatility and lower risk tolerance among investors, the slope of the demand curve in the JGB market (in Chart 6) would likely steepen, which would lead to an increase in the coefficients for the impact of JGB purchases on interest rates above the historical average captured by the model.

[34] Waller [2024] points out that the effect of government bond purchases on the market can differ substantially depending on central banks' communication accompanying such purchases or quantitative tightening, such as whether they are open-ended or closed-ended, and the degree to which such purchases or tightening are predictable. The model in this paper incorporates this idea and uses the expected share of future JGB holdings as one of the variables based on the assumption that market participants anticipate the future path of JGB purchases over the next two years. However, this means that if the way market participants incorporate information and form expectations changes, the assumptions of the model would also need to be changed, which would potentially change predictions derived by the model.

[35] The Fed and the ECB also currently conduct monetary policy using short-term interest rates as their primary policy tool, while maintaining the size of their balance sheets at ample levels. See, for example, the Fed's "Principles for Reducing the Size of the Federal Reserve's Balance Sheet," published in January 2022.

disappear.[36] On the other hand, regardless of the amount of JGB purchases in the near term, the BOJ's JGB holdings are expected to remain at a high level for the time being. Given the estimation results in this paper, this would imply that the BOJ's JGB purchase program will continue to affect the formation of the yield curve, mainly through the stock effect. That said, it is important to note that, as discussed above, the quantitative results presented in this paper should be interpreted with considerable latitude. Recent studies have highlighted that the magnitude of the effect on long-term interest rates may differ between periods in which the central bank increases and decreases its holdings of JGBs.[37] Keeping these points in mind, it is important to further deepen our understanding of the effects of central bank purchases and holdings of government bonds on long-term interest rates.

[36] At the March 2024 Monetary Policy Meeting, the BOJ decided that in the case of a rapid rise in long-term interest rates, it will make nimble responses by, for example, increasing the amount of JGB purchases, regardless of the monthly schedule of JGB purchases. Although it is difficult to quantify the effect of this statement using the analytical framework in this paper since it does not indicate a specific target level for the long-term yield in advance, it is expected to contribute to the stable formation of long-term interest rates in a manner similar to the setting of an upper bound under YCC.

[37] See, for example, Schnabel [2023, 2024] and Ramsden [2023]. At a recent event (the US Monetary Policy Forum), Kristin Forbes, a professor at MIT, presented an event study analysis (Du et al. [2024]) using data from seven central banks that have already reduced their government bond holdings, including the Fed and the ECB, and pointed out that announcements of reductions in government bond holdings significantly raise long-term interest rates, but that, the quantitative magnitude of the effect is relatively small compared to the effect of the announcements of increases in government bond purchases. She then discussed with Fed officials the reasons for and background to this in terms of differences in economic and financial conditions and central bank communication. (See also, for example, Waller [2024] and Logan [2024]).

References

Altavilla, C., G. Carboni, and R. Motto [2015], "Asset Purchase Programmes and Financial Markets: Lessons from the Euro Area," ECB Working Paper, No.1864.

Aoki, K. [2023], "The Bank of Japan's Balance Sheet." In Gürkaynak, R. S. and J. H. Wright (ed.), *Research Handbook of Financial Markets*, Chapter 3 ,56-78, Edward Elgar Publishing.

Amamiya, M. [2017], "History and Theories of Yield Curve Control," Keynote Speech at the Financial Markets Panel Conference to Commemorate the 40th Meeting.

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),* September 2016.

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

Bank of Japan [2024] *Outlook for Economic Activity and Prices*, April 2024.

Bauer, M. D., and G. D. Rudebusch [2014], "The Signaling Channel for Federal Reserve Bond Purchases," *International Journal of Central Banking*, 10(3), 233-289.

Bernanke, B. S., and V. Reinhart [2004], "Conducting Monetary Policy at Very Low Short-Term Interest Rate," *American Economic Review*, 73(4), 257-276.

Bernanke, B. S., V. Reinhart, and B. Sack [2004], "Monetary Policy Alternatives at the Zero Bound: An Empirical Assessment," *Brookings Papers on Economic Activity*, 2, 1-100.

Bernanke, B. S. [2016], "The Latest from the Bank of Japan," Brookings Institution Ben Bernanke's Blog, September 21, 2016.

Bernanke, B. S. [2020], "The New Tools of Monetary Policy," *American Economic Review*, 110(4), 943-983.

Bank for International Settlements [2023], "Central Bank Asset Purchases in Response to the Covid-19 Crisis," CGFS Papers No. 68.

Chung, H., E. Gagnon, J. Hebden, K. Kim, B. Schlusche, E. Till and D. Vilán [2023], "Balance Sheet Policies in an Evolving Economy: Some Modelling Advances and Illustrative Simulations," FEDS Notes, February 3, 2023.

D'Amico, S., and King, T. B. [2013], "Flow and Stock Effects of Large-scale Treasury Purchases: Evidence on the Importance of Local Supply," *Journal of Financial*

Economics, 108(2), 425-448.

Du, W., K. Forbes, and M. Luzzetti [2024], "Quantitative Tightening Around the Globe: What Have We Learned?" 2024 US Monetary Forum, February 28.

Eggertsson, G. B. and M. Woodford [2003], "Zero bound on Interest Rates and Optimal Monetary Policy," *Brookings Papers on Economic Activity*, 1, 139-233.

Federal Open Market Committee [2020], *Minutes of the Federal Open Market Committee*, June 9-10, 2020.

Fujiki, H., and S. Shiratsuka [2002], "Policy Duration Effect under the Zero Interest Rate Policy in 1999–2000: Evidence from Japan's Money Market Data," *Monetary and Economic Studies*, January 2002, 1-32.

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

Fukunaga, I., N. Kato, and J. Koeda [2015], "Maturity Structure and Supply Factors in Japanese Government Bond Markets," *Monetary and Economic Studies*, 33, 37–53.

Gagnon, J., M. Raskin, J. Remache, and B. P. Sack [2011], "Large-scale Asset Purchases by the Federal Reserve: Did They Work?" *Economic Policy Review*, 17(1), 41.

Gilchrist, S., and E. Zakrajšek [2013], "The Impact of the Federal Reserve's Large-Scale Asset Purchase Programs on Corporate Credit Risk," *Journal of Money, Credit and Banking*, 45(2), 29-57.

Gilchrist, S., B. Wei, V. Z. Yue, and E. Zakrajšek [2021], "The Fed Takes on Corporate Credit Risk: an Analysis of the Efficacy of the SMCCF," BIS Working Papers No.963.

Hattori, T and J. Yoshida [2023], "Yield Curve Control," *International Journal of Central Banking*, 19(5), 403-438.

Higgins, M., and T. Klitgaard [2020], "Japan's Experience with Yield Curve Control," Federal Reserve Bank of New York, Liberty Street Economics, June 22, 2020.

Ichiue, H., and Y. Shimizu [2012], "Determinants of Long-term Yields: A Panel Data Analysis of Major Countries," *Japan and the World Economy*, 34–35, 44-55.

Ihrig, J., E. Klee, C. Li, M. Wei and J. Kachovec [2018], "Expectations about the Federal Reserve's Balance Sheet and the Term Structure of Interest Rates," *International Journal of Central Banking*, 14(2), 341-390.

Imakubo, K., and Nakajima, J. [2015], "Estimating Inflation Risk Premia from Nominal and Real Yield Curves Using a Shadow-rate Model," Bank of Japan Working Paper Series, No.15-E-1.

Izawa, K., Y. Takahashi, S. Yoneyama [2024], "Measuring Policy Effects since the Introduction of Quantitative and Qualitative Monetary Easing (QQE): An Analysis of Policy Effects on the Economy and Prices Using the Macroeconomic Model Q-JEM," mimeo.

Katagiri, M., and K. Takahashi [2017], "Do Term Premiums Matter? Transmission via Exchange Rate Dynamics," Bank of Japan Working Paper Series, No.17-E-7.

Koeda, J., and Y. Ueno [2022], "A Preferred Habitat View of Yield Curve Control," Bank of Japan Working Paper, 22-E-7.

Koeda, J. and B. Wei [2023] "Quantifying Forward Guidance and Yield Curve Control," mimeo.

Koeda, J. and B. Wei [2024] "Yield Curve Control in Japan," mimeo.

Krishnamurthy, A., and A. Vissing-Jorgensen [2011], "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy," *Brookings Papers on Economic Activity*, 43(2), 215-287.

Li, C., and M. Wei [2013], "Term Structure Modeling with Supply Factors and the Federal Reserve's Large-scale Asset Purchase Programs," *International Journal of Central Banking*, 9(1), 3-39.

Logan, L. K. [2024], "Discussion of ‘Quantitative Tightening Around the Globe: What Have We Learned?’ by Wenxin Du, Kristin Forbes and Matthew Luzzetti," Remarks at the 2024 U.S. Monetary Policy Forum, March 1, 2024.

Lucca, D., and J. Wright [2024], "The Narrow Channel of Quantitative Easing: Evidence from YCC Down Under," *Journal of Finance*, 79(2), 1055-1085.

Nakamura, K., and T. Yagi [2017], "Fiscal Conditions and Long-term Interest Rates," *Monetary and Economic Studies*, November 2017, 59-88.

Ochi, K., and M. Osada [2023], "Developments in Corporate Bond Spreads at Issuance," Bank of Japan Review, 23-E-8.

Ochi, K., and M. Osada [2024], "Market Functioning in the Japanese Corporate Bond Market," Bank of Japan Working Paper, 24-E-5.

Oda, N. and K. Ueda [2007], "The Effects of the Bank of Japan’s Zero Interest Rate

Commitment and Quantitative Monetary Easing on the Yield Curve: A Macro-finance Approach," *The Japanese Economic Review*, 58, 303-328.

Ramsden, D. [2023], "Quantitative Tightening: The Story so far" Speech at the Bank of England, organized by the Money Macro and Finance Society, 19 July 2023.

Reserve Bank of Australia [2022], *Review of the Yield Target*.

Rose, J [2021], "Yield Curve Control in the United States: 1942 to 1951," Federal Reserve Bank of Chicago Economic Perspectives, 2/2021.

Schnabel, I. [2023], "Quantitative Tightening: Rationale and Market Impact," Speech at the Money Market Contact Group Meeting, March 2, 2023.

Schnabel, I. [2024], "The Benefits and Costs of Asset Purchases," Speech at the 2024 BOJ-IMES Conference on "Price Dynamics and Monetary Policy Challenges: Lessons Learned and Going Forward," May 28, 2024.

Shirakawa, M. [2002], "One Year under 'Quantitative Easing'," Bank of Japan IMES Discussion Paper, No.2002-E-3.

Shirakawa, M [2008], *Modern Monetary Policy in Theory and Practice*, Nikkei Publishing Inc (available only in Japanese).

Shiratsuka, S. [2024], "What Does the Yield Curve Control Policy Do?," Keio-IES Discussion Paper Series, DP2024-002.

Sudo, N., and M. Tanaka [2021], "Quantifying Stock and Flow Effects of QE," *Journal of Money, Credit and Banking*, 53(7), 1719-1755.

Ueda, K. [2005], *Zero Kinri to no Tatakai*, Nikkei Publishing Inc (available only in Japanese).

Ueda, K. [2012], "The Effectiveness of Non-Traditional Monetary Policy Measures: The case of the Bank of Japan," *The Japanese Economic Review*, 63(1), 1-22.

Ugai, H. [2007], "Effects of the Quantitative Easing Policy: A Survey of Empirical Analyses," *Monetary and Economic Studies*, March 2007, 1-48.

Vayanos, D., and J. L. Vila [2021], "A Preferred-Habitat Model of the Term Structure of Interest Rates," *Econometrica*, 89(1), 77–112.

Waller, C. J. [2024] "Thoughts on Quantitative Tightening, including Remarks on the Paper 'Quantitative Tightening around the Globe: What Have We Learned?'" Remarks at the 2024 U.S Monetary Policy Forum, March 1, 2024.

Appendix A. Estimation Method for the *Expected Future Share of the BOJ's JGB Holdings (Adjusted for Interest Rate Risk)*

This appendix presents the method we use for constructing the expected future share of BOJ holdings of JGBs (adjusted for interest rate risk) introduced in Section 2 and used in the analysis in Section 4. Specifically, we first calculate (1) the *risk-adjusted share of the BOJ's JGB holdings*, which takes interest rate risk with respect to the BOJ's JGB holdings into account. Next, (2) we estimate the *expected future share of the BOJ's JGB holdings (adjusted for interest rate risk)* based on the actual and the announced amount of purchases by the BOJ.

A.1. *Risk-adjusted share of the BOJ's JGB holdings*

The amount of interest rate risk of a bond (the change in the bond price when the interest rate changes by one unit) depends on its remaining maturity and the level of the interest rate.[38] Performing a quadratic approximation using a Taylor expansion around interest rate r for bond price P, the change in the bond price when the bond interest rate changes by Δr using bond duration D and convexity C can be expressed as follows:

$$\frac{P(r+\Delta r)-P(r)}{P} \approx \frac{1}{P}\frac{dP}{dr}\Delta r + \frac{1}{2}\frac{1}{P}\frac{d^2P}{dr^2}(\Delta r)^2 = -D\Delta r + \frac{1}{2}C(\Delta r)^2 \qquad \text{(A.1)}$$

where, approximating convexity C by D^2 for simplicity, the amount of interest rate risk ($-\Delta P/P$) of each bond issue for a 1% rise in interest rates (Δr = 1%) can be calculated as a function of its remaining maturity D (R^D).[39] We use this approximate relationship to convert the BOJ's JGB holdings and overall JGB issuance to a risk amount basis.

We start by calculating the BOJ's JGB holdings by maturity (remaining maturity) using the "Japanese Government Bonds Held by the BOJ" statistics on the BOJ's JGB holdings published monthly by the BOJ.[40] In other words, the amount of JGB holdings by maturity can be calculated using information on JGB holdings by issue and the scheduled redemption date of JGBs of each issue.

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[38] The possibility that bonds are redeemed or sold prior to maturity in response to changes in interest rates should also be taken into account. However, with some exceptions in the past, the BOJ holds JGBs until maturity without selling them. Given this, the BOJ employs the amortized cost method for the valuation of JGBs.

[39] Specifically, R^D can be calculated as $R^D = -\Delta P/P = 0.01D - 0.0001D^2/2$.

[40] Treasury discount bills are excluded from the analysis because purchases and holdings of such assets likely have little impact on long-term interest rates. Floating-rate bonds and inflation-indexed bonds, which only account for a small share of BOJ holdings, are also excluded, and only fixed-rate JGBs are included.

The "Japanese Government Bonds Held by the BOJ" statistics do not contain data prior to May 2001. We therefore retroactively estimate the amount of interest rate risk held by the BOJ for the period prior to May assuming a linear relationship between the interest rate risk amount and semiannual data on the average remaining maturity of JGBs, and then convert them to monthly data through linear interpolation.

In converting JGB holdings to an interest rate risk basis, we follow previous studies (e.g., Li and Wei [2013]) and standardize the amount of JGBs outstanding to the equivalent amount of 10-year bonds that contain the same amount of interest rate risk (i.e., the 10-year equivalent value). Specifically, risk-adjusted JGB holdings ($JGBRISK_t^D$) for each maturity are calculated by multiplying the amount of JGB holdings (JGB_t^D) for each maturity by the 10-year JGB equivalent risk amount (R^D/R^{10Y}) and adding them together for all maturities to obtain the aggregate risk-adjusted value ($JGBRISK_t$).

$$JGBRISK_t = \sum_D JGBRISK_t^D = \sum_D \left(\frac{R^D}{R^{10Y}} \times JGB_t^D \right) \tag{A.2}$$

A.2. *Expected Future Share of the BOJ's JGB Holdings*

Next, we construct the expected future share of the BOJ's JGB holdings (adjusted for interest rate risk) taking market participants' expectations based on the actual purchase amount and announced planned amount of purchases by the BOJ into account.

There are several possible ways to incorporate market participants' expectations of the BOJ's future JGB holdings. The first is to use surveys of market participants. Equiza et al. [2023], who examine the effect of the ECB's asset purchases, for example, obtain market participants' expectations of the future pace of government bond purchases at each date from a monthly survey of economists conducted by Bloomberg and use these to estimate expected future government bond holdings.[41] The second approach is to assume that market participants forecast the future path of purchases based on publications such as central bank releases. An example of a study following this approach is that by Ihrig et al. [2018], who analyze the effect of the FRB's three quantitative easing programs (LSAP1, LSAP2, and LSAP3) implemented in the U.S. in the wake of the global financial crisis. They estimate the expected future outstanding amount of the FRB's government bond holdings assuming that market participants form their expectations based on the FRB's announcements (about the total purchases of assets such as long-term government bonds and the pace of those purchases). For our analysis in Section 4, we tried to estimate the long-term interest rate model from 1997 but were unable to obtain survey-based information on market participants' expectations for the entire period. Therefore, as in Ihrig et al. [2018], we make various assumptions regarding the formation of market participants' expectations using available information on the BOJ's purchases of JGBs.

Specifically, we estimate the expected future (two-year ahead) share of BOJ holdings

[41] Since Bloomberg's survey does not provide the expected maturity structure of purchases, the amount of interest rate risk of future holdings is calculated by combining future pace of purchases at each date with information on the maturity structure announced separately by the ECB.

based on the following assumptions for each subperiod.[42] (1) For the period after the introduction of the QEP (from March 2001 to September 2010[43]), we assume that the monthly pace of purchases at each point announced by the BOJ would continue over the next two years. (2) After the introduction of CME (from October 2010 to March 2013), the BOJ established its Asset Purchase Program as a temporary measure, so we add the scheduled purchase amount of that program to the former purchase expectations.[44] (3) For the period between the introduction of QQE and the introduction of YCC (from October 2010 to August 2016), we assume that market participants expected the pace of purchases over the next two years to be in line with the announced monthly pace of JGB purchases (at an annual pace of about 50 trillion yen until October 2013, and about 80 trillion yen from November 2014). Finally, (4) for the period after the introduction of YCC (from September 2016 onward), the JGB holdings in two years' time implied by the monthly pace of purchases announced in the "Schedule of Outright Purchases of Japanese Government Bonds" released monthly by BOJ is used. Since the "Schedule of Outright Purchases of Japanese Government Bonds" indicates only the upper and lower limits of the purchase amount for each remaining maturity, the average of the upper and lower limits is used as the scheduled purchase amount.[45] Chart A.1 shows the expected amount of the BOJ's JGB purchases over the next two years based on the above assumptions.

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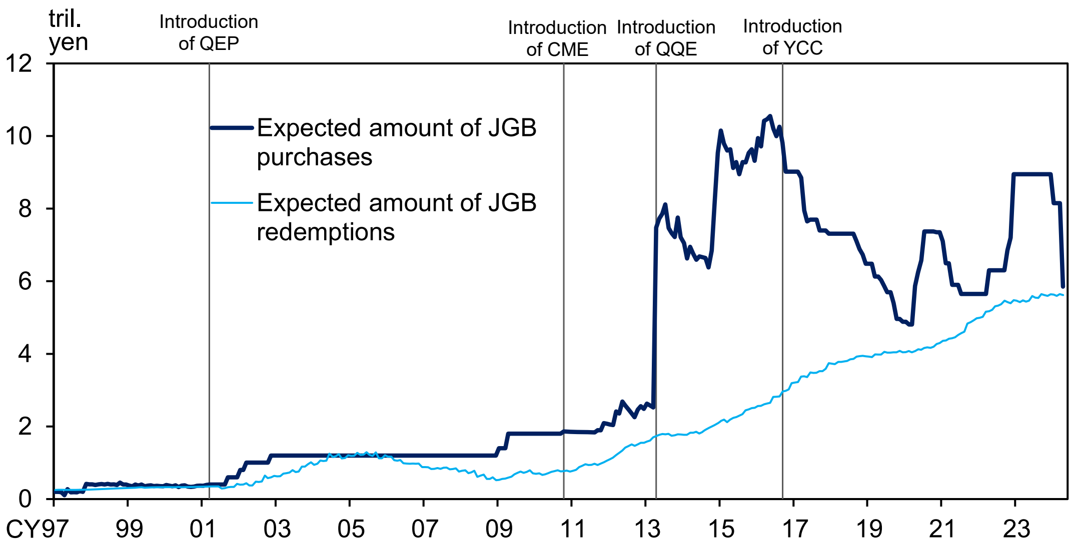
[42] Li and Wei [2013] and Ihrig et al. [2018], using a term structure model of interest rates, argue that shocks to the expected future bond supply have the effect of pushing down the current term premium, and that the more distant the future shock occur, the more its effect is discounted. Therefore, in their models, shocks that occur in the distant future only have a negligible effect on the current term premium. Consequently, in our analysis we focus on the expected JGB holdings over the next two years only.

[43] Before the introduction of the QEP (i.e., prior to March 2001), asset purchases were not linked directly to monetary policy. Given this, the amount of JGB holdings two years ahead is calculated assuming that the monthly purchases of long-term JGBs at each point in time would continue for the next two years.

[44] We assume that under the CME Asset Purchase Program monthly JGB purchases were implemented at a constant pace until the target amount of purchases announced at each point in time was reached.

[45] From April 2021 to November 2022, the planned amount of purchases was published instead of the range.

Chart A.1. Expected Amount of the BOJ's JGB Purchases and Redemptions over the Next Two Years (Per Month)



Note: Latest data are as of April 2024.
Source: Bank of Japan.

The expected amount of the BOJ's JGB holdings over the next two years can be calculated by subtracting the expected redemption amount of JGBs over the next two years from the expected purchase amount calculated above and adding it to the amount of JGB holdings at each point in time. The redemption amount is calculated by adding up (1) the amount of holdings at each point in time whose redemption date falls within the next two years and (2) the portion of scheduled purchases over the next two years that will mature within the next two years.[46]

Taking interest rate risk into account, we calculate the expected JGB holdings for each maturity, and then convert them to the 10-year equivalent amount using the above equation (A.2) and finally aggregate the amounts.[47]

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[46] For the period prior to June 2001, data for BOJ JGB holdings by maturity is not publicly available. We therefore assume that the ratio of the redemption amount over the next two years to the outstanding amount of JGBs is constant and equals the average for the period from June 2001 to May 2002.

[47] In order to calculate expected JGB holdings by maturity, it is necessary to make assumptions regarding the composition of future JGB purchases by maturity.

For the period since the introduction of QQE, we use the BOJ's purchase schedule by remaining maturity (up to 1 year, more than 1 year and up to 3 years, more than 3 years and up to 5 years, more than 5 years and up to 10 years, more than 10 years and up to 25 years, and more than 25 years) published each month.

On the other hand, this information was not available for the period before the introduction of QQE. Therefore, we use the actual maturity structure of each month's purchases (moving averages for the six months before and after the purchases to smooth out short-term fluctuations). For the period before May

Lastly, expected future JGB issuance by the government, which is the denominator of the expected future share of the BOJ's JGB holdings (adjusted for interest rate risk) in the total amount of JGBs outstanding, is calculated based on the simplifying assumption that at each point in time the pace of issuance over the next two years is the same as that over the past two years. The maturity structure of JGBs is assumed to remain constant on a stock basis. Chart 7 shows the expected future share of the BOJ's JGB holdings (adjusted for interest rate risk) based on the above assumptions.

References

Equiza, J., R. Gimeno, A. Moreno, and C. Thomas [2023], "Evaluating Central Bank Asset Purchases in a Term Structure Model with a Forward-looking Supply Factor," BANCO DE ESPAÑA Working Papers, No.2303.

Ihrig, J., E. Klee, C. Li, M. Wei and J. Kachovec [2018], "Expectations about the Federal Reserve’s Balance Sheet and the Term Structure of Interest Rates," International Journal of Central Banking, 14(2), 341-390.

Li, C., and M. Wei [2013], "Term Structure Modeling with Supply Factors and the Federal Reserve's Large-scale Asset Purchase Programs," International Journal of Central Banking, 9(1), 3-39.

2001, when issue-specific information is not available, we assume perfect foresight and that market expectations are equal to the realized value two years ahead. (Here, the realized value refers to the ratio of the BOJ's JGB holdings adjusted for interest rate risk to the BOJ's JGB holdings not adjusted for interest rate risk).

Appendix B. Estimation Methodology for the *Probability that the Long-Term Yield Might Exceed the YCC Range*

This appendix explains how we calculate the probability that the long-term yield might exceed the YCC range introduced in Section 3 and used in the analysis in Section 4. Specifically, we (1) estimate the expected future interest rate distribution using data from interest rate swaptions with the 10-year OIS rate as the underlying price and (2), using this distribution, calculate the probability that the long-term interest rate might exceed the upper or lower bound of the YCC target range 3 months ahead priced in by market participants.

The expected future interest rate distribution is estimated employing the approach proposed by Malz [2014] utilizing the "volatility smile" -- the tendency of a plot of the relationship between the implied volatility (IV) and the strike price to be a convex curve -- incorporated into swaption prices.[48]

Specifically, we start by expressing the price $c(t, X, \tau)$ of a European call option at time t using the following equation:

$$c(t, X, \tau) = e^{-r_t \tau}\, \tilde{E}_t[\max(S_t - X, 0)] = e^{-r_t \tau} \int_X^{\infty} (s - X)\tilde{\pi}_t(s)ds \qquad \text{(B.1)}$$

where, for a 3-month interest rate swaption with a 10-year OIS rate as the underlying price, S_t is the price of the underlying asset (=OIS rate) at time t, X is the strike price, τ is the remaining term ($\tau = T - t$ when the maturity of the underlying asset is T), $\tilde{\pi}_t(s)$ is the probability density function for the future distribution of the underlying asset price, and r_t is the risk-free rate. Here, the probability density function $\tilde{\pi}_t(X)$, which we ultimately want to calculate, integrated over the cumulative distribution function $\tilde{\Pi}_t(X)$ is derived by partial differentiation of the option price by strike price X as follows:

$$\tilde{\Pi}_t(X) = \int_X^{\infty} \tilde{\pi}_t(s)ds = 1 + e^{r_t \tau} \frac{\partial}{\partial X} c(t, X, \tau) \qquad \text{(B.2)}$$

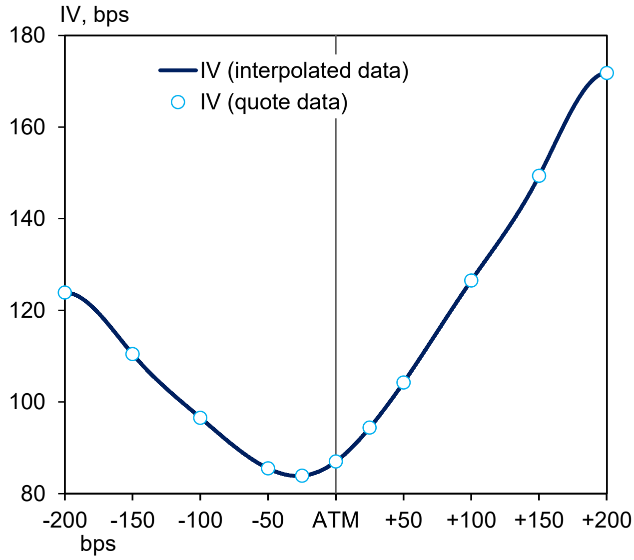
Using this equation, we can calculate the expected future interest rate distribution using option price data, if the relationship with the strike price can be derived. However, in practice, strike prices X of traded options are discrete, so that a continuous relationship between option prices and strike prices cannot be observed. We therefore need to somehow estimate option prices corresponding to strike prices at which no trades take place through interpolation. However, since the relationship between option prices and strike prices is

[48] This method proposed by Malz [2014] can be also applied to the future distribution of the exchange rate, as recently done by Yoneyama et al. [2024].

highly nonlinear, it is not easy to make accurate interpolated estimates (Jiang and Tian [2005]). For this reason, in practice, probability densities are often estimated by interpolating IV data that show continuous changes with respect to the strike price, and then convert the values to option prices (Malz [2014]).

In this paper, we use IV quote data for 3-month forward 10-year interest rate swaptions, which we obtain from *LSEG Eikon*. For IVs corresponding to the 11 strike prices for which data are available (namely, ATM =at the Money: when the strike price equals the market price, ATM ±25 bps, ATM ±50 bps, ATM ±100 bps, ATM ±150 bps, and ATM ±200 bps), we estimate the cubic spline function, which is often used in previous research, for interpolation.[49] Looking at the estimated IV functions in Chart B.1, the functions are relatively smooth, and a so-called "volatility smile" shape can actually be observed, with volatility bottoming out around ATM and increasing at both ends.

Chart B.1. IV Function Calculated from Swaption Data



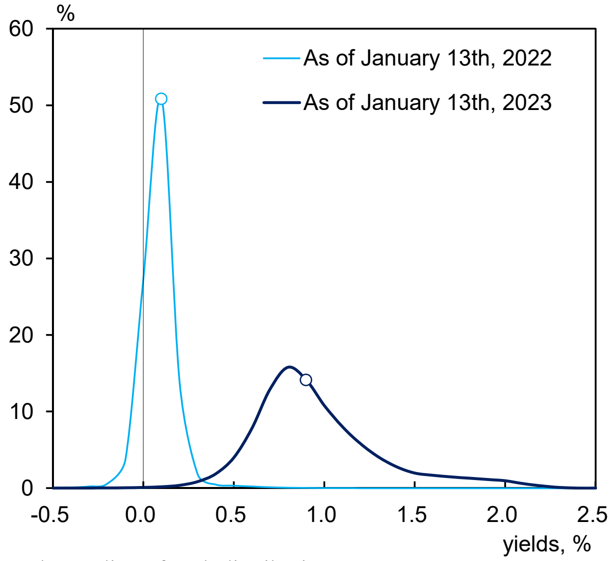
Note: As of January 13th, 2023.
Sources: Bloomberg; LSEG Eikon.

Chart B.2 shows the expected future interest rate distribution calculated from the obtained IV function. Since there is a one-to-one relationship between option prices and the

[49] Note that when nonparametric methods such as spline interpolation are used, extreme unevenness can be observed in the value of the IV at each strike price, and the interpolated IV can also be negative. We check that the interpolated IV in this paper is non-negative for all periods.

IV, it is possible to numerically calculate the expected distribution at each point in time.[50,51] The chart shows that the expected distribution at the beginning of 2022 was concentrated around zero percent under the YCC framework. However, at the beginning of 2023, when long-term yields came under upward pressure, the distribution shifted significantly to the right and the dispersion became larger with a thicker right tail. This indicates that uncertainty about future interest rate levels had increased, and that some investors were increasingly expecting the abolition of YCC and a significant rise in interest rates.

Chart B.2. Expected Future 10-year Interest Rate Distribution 3 Months Ahead



Note: The circles denote the median of each distribution.
Sources: Bloomberg; LSEG Eikon.

The probability that long-term interest rates exceed or fall below a specific level three months from now can be calculated using the expected interest rate distribution at each point in time calculated as described above. Chart 11 shows the probabilities at each point in time that long-term interest rates exceed the upper or lower bounds of the YCC targeted range or offer rate for fixed-rate purchase operations three months later (see Chart 8 for the targeted range at each point in time).

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50 The call option price $c(t, X, \tau)$ can be represented by the option valuation function $V(S_t, X, \tau, \sigma(t, X, \tau))$ with the IV as a variable using the Black model. However, in Japan, yields have been negative in recent years. Since the Black model does not take this possibility into account, it cannot depict option prices. For this reason, *LSEG Eikon* converts option prices and IVs using a normal model (the Bachelier model) that assumes that swap rates follow a normal distribution as its standard model.

51 In calculating the distribution, we assume the risk-free rate r_t to be zero since short-term interest rates in Japan are around zero percent.

Since IVs for LIBOR-based swaptions were used prior to May 25, 2022, we use the LIBOR-OIS spread to convert the distribution to an OIS-based distribution, assuming a parallel shift in the overall distribution. For missing portions of the IV data for the 11 strike prices, parameters were estimated using only available data and interpolation estimation was performed.

References

Malz, A. M. [2014], "A Simple and Reliable Way to Compute Option-Based Risk-Neutral Distributions," Federal Reserve Bank of New York Staff Reports, No.677.

Jiang, G. J., and Tian, Y. S. [2005], "Model Free Implied Volatility and Its Information Content," Review of Financial Studies, 18, 1305-1342.

Yoneyama, A., A. Tsuchiya., and N. Fukuma [2024], "Changes in Risk Perceptions on Yen Interest Rates and Exchange Rates Observed in Options Markets: Developments in Implied Probability Distributions amid Rate Hikes in the United States and Europe from 2022 to 2023," Bank of Japan Review, 24-E-8.

Appendix C. Detailed Estimation Results of Interest Rate Functions

Chart C.1. Detailed Estimation Results for Model 5 in Chart 16

(1) Dependent Variable: Expected Short-term Rate Component for Each Maturity

Dependent variable	1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year
Constant	0.075 ***	0.102 ***	0.145 ***	0.192 ***	0.240 ***	0.291 ***	0.341 ***	0.388 ***	0.433 ***	0.476 ***
10-year U.S. Treasury yields	0.005	0.018 ***	0.029 ***	0.040 ***	0.048 ***	0.056 ***	0.063 ***	0.069 ***	0.074 ***	0.078 ***
Uncollateralized overnight call rate	0.708 ***	0.811 ***	0.853 ***	0.875 ***	0.886 ***	0.875 ***	0.858 ***	0.838 ***	0.818 ***	0.798 ***
CPI (less fresh food and energy)	0.020 ***	0.034 ***	0.047 ***	0.057 ***	0.065 ***	0.071 ***	0.075 ***	0.078 ***	0.080 ***	0.082 ***
Risk-adjusted share of BOJ's JGB holdings in total	-0.004 ***	-0.005 ***	-0.006 ***	-0.007 ***	-0.008 ***	-0.008 ***	-0.009 ***	-0.009 ***	-0.009 ***	-0.009 ***
Monthly change in JGB holdings	-0.049 **	-0.081 ***	-0.113 ***	-0.139 ***	-0.163 ***	-0.177 ***	-0.187 ***	-0.195 ***	-0.202 ***	-0.208 ***
Adjusted R-squared	0.692	0.758	0.790	0.808	0.819	0.826	0.830	0.832	0.833	0.833
AIC	-1.636	-1.527	-1.412	-1.321	-1.243	-1.186	-1.142	-1.110	-1.089	-1.077
Estimation Period	January 1997 to March 2024									

(2) Dependent Variable: Term Premium for Each Maturity

Dependent variable	1-year	2-year	3-year	4-year	5-year	6-year	7-year	8-year	9-year	10-year
Constant	0.053 **	0.045 **	0.023	0.001	-0.053	-0.077	-0.087	-0.056	0.001	0.019
10-year U.S. Treasury yields	0.010	0.027 ***	0.047 ***	0.075 ***	0.103 ***	0.126 ***	0.146 ***	0.157 ***	0.157 ***	0.159 ***
Risk-adjusted share of BOJ's JGB holdings in total	0.000	-0.002	-0.002	-0.003	-0.002	-0.003	-0.004	-0.006 *	-0.008 **	-0.009 **
Expectation of future changes in JGB holdings	-0.006 ***	-0.005 ***	-0.005 ***	-0.006 ***	-0.007 ***	-0.009 ***	-0.010 ***	-0.011 ***	-0.013 ***	-0.014 ***
Ratio of fixed-rate purchase operations to JGB issuance	0.001 **	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.002 **
Probability that the upper bound of the YCC range is exceeded (from Sep. 2016 to Apr. 2022, from Nov. 2023 to Mar. 2024)	-0.010 **	-0.011 **	-0.019 ***	-0.026 ***	-0.035 ***	-0.040 ***	-0.043 ***	-0.044 ***	-0.044 ***	-0.046 ***
Probability that the offer rate of fixed-rate purchase operations for consecutive days is exceeded(from May. 2022 to Oct. 2023)	-0.016 ***	-0.019 ***	-0.032 ***	-0.042 ***	-0.048 ***	-0.054 ***	-0.056 ***	-0.056 ***	-0.056 ***	-0.059 ***
Probability that the lower bound of the YCC range is exceeded	-0.010 *	0.001	0.010	0.018 *	0.023 **	0.027 **	0.027 **	0.028 **	0.026 **	0.025 **
Adjusted R-squared	0.450	0.609	0.687	0.731	0.760	0.773	0.773	0.785	0.803	0.813
AIC	-2.085	-2.198	-1.782	-1.340	-1.046	-0.747	-0.488	-0.345	-0.328	-0.290
Estimation Period	January 1997 to March 2024									

Notes: 1. ***, **, and * denote statistical significance at the 1, 5, and 10% levels, respectively.
2. In the estimations, U.S. Treasury yields for the corresponding maturities are used.

Sources: Bank of Japan; Ministry of Internal Affairs and Communications; Bloomberg; LSEG Eikon.