Quantitative Easing, Scarcity, and Spotlight Effects on Liquidity in the Government Bond Market

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Abstract

We examine the impact of the Quantitative Easing (QE) programs implemented by one of the largest central banks in the world on market liquidity in the sovereign bond market. We do so in the context of the Large Scale Asset Purchase (LSAP) program of the Bank of Japan (BoJ) and distinguish between two opposing effects of QE on the yield and liquidity of Japanese Government Bonds (JGBs): the “scarcity effect,” which results from the reduction in liquidity as a consequence of shrinkage in the available bonds in the market, and the “spotlight effect,” which improves liquidity, arising from focusing attention on individual bonds selected for purchase by the central bank. The spotlight effect thus has an immediate positive impact on bond liquidity; on the other hand, the scarcity effect is only gradually manifested as a negative impact on liquidity. Since the LSAP repeatedly involved the purchase of significant amounts of individual securities, it is important to disentangle these two effects from each other to assess the overall impact. In the case of the BoJ’s LSAP between 2011 and 2016, we find that, indeed, government bonds show an improvement in liquidity through the spotlight effect and then a deterioration in liquidity through the scarcity effect. The spotlight effect is associated with the BoJ’s clear announcements of the programs and purchases in subsequent operations. The scarcity effect is amplified in the latter’s Quantitative and Qualitative Easing and when the BoJ’s bond holding ratio for particular maturities rises above 59% and 37% for three- to 10-year bonds and bonds over 10 years, respectively, indicating the presence of a ratio threshold above which the relation between yield change and time to maturity is altered. Our results suggest, therefore, that an aggressive QE program can eventually adversely affect the government bond market’s liquidity and that the execution of such an LSAP program requires caution.

JEL classification: C54, E43, E52, E58, G12, G14
Keywords: Sovereign bonds, quantitative easing, market liquidity, scarcity

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1 Introduction

Since the global financial crisis in 2008, the major central banks of the world have engaged in unconventional monetary policy in the form of quantitative easing (QE) programs to stimulate their economies. These policies have been particularly evident in Japan, where the Bank of Japan (BoJ) has been implementing a Large Scale Asset Purchase (LSAP) program, purchasing several assets, including Japanese Government Bonds (JGBs), shares of real estate investment trusts (REITs), and even equity exchange-traded funds (ETFs), with the objective of stimulating the economy through a reduction in interest rates. Predictably, these programs have had an ameliorative effect on bond yields in the JGB market, as has been widely noted. However, they have also had an impact on market liquidity in the JGB market that has not been adequately studied.

In examining the market liquidity effects of QE, it is important to distinguish between two opposing effects of QE on the yield and liquidity of JGBs: the “scarcity effect,” which affects liquidity and price impacts due to the shrinkage in the available bonds in the market ("supply shock"), and the “spotlight effect,” from attention on individual bonds selected for purchase by the central bank, which causes an improvement in bond prices and liquidity.

The LSAPs conducted by the BoJ are implemented by a reverse auction mechanism similar to that used by the Federal Reserve System’s (Fed) QE auctions (Song and Zhu 2016). For each purchase operation, the BoJ announces the total amount and the maturity bucket of the JGBs to be purchased. The auction results are disclosed only to dealers who submit successful offers. The spotlight effect created by the LSAP arises because the BoJ repeatedly purchases significant amounts of the same bonds. Such an action creates unique trading opportunities for bonds in the target list for dealers and other investors. Hence, inclusion of a bond, especially off-the-run bonds, in the BoJ’s target list draws keen attention from bond dealers and investors, resulting in positive effects for bond prices. Thus, the spotlight effect has an immediate impact on the price and liquidity of government bonds and is conceptually different from the broad signaling effect of the QE announcement, because it is caused not only by information but also by the interaction between the central bank and dealer actions in each operation.

Simultaneously, the massive purchases of sovereign bonds by the central bank lead to “scarcity” which worsens liquidity, that is, the ability of traders to buy or sell in a timely manner without limitations in amount or a large market impact cost; then, this adverse effect will be “priced” in the sense argued by Amihud and Mendelson (1986) in their classic paper and several others who followed their lead. Therefore, the positive effect of large-scale bond purchases by the central bank will, at least partially, be nullified by the negative effect through the worsening of liquidity due to a reduction in the “free float” of these bonds, that is, the bonds available for trading in the market.

Apart from the scarcity effect highlighted above, which causes liquidity to worsen with attendant negative consequences for bond prices, there is the opposite spotlight effect mentioned earlier. Thus, the LSAP creates both a scarcity effect and a spotlight effect, which have opposing effects on bond yields and liquidity. Which of the two effects dominates is an open question that can only be established empirically, on both a bond-by-bond basis and a period-by-period basis. This is what we aim to do in this paper for the LSAPs of the BoJ.
In the spirit of preferred habitat theory proposed by Modigliani and Sutch (1966), Vayanos and Vila (2009), Greenwood and Vayanos (2014), and D’Amico and King (2013), among many others, identify two main channels, duration risk and scarcity effects, in addition to the signaling effect of the QE announcement. This analysis focuses attention on the increase in bond prices and the reduction in bond yields, which are an important aspect of the effectiveness of QE programs. However, this literature is largely silent on the effects of unconventional monetary policies on market liquidity in the sovereign bond market. We contribute to the literature by showing spotlight and scarcity effects in the case of the BoJ’s quantitative and qualitative easing (QQE). We extend the framework proposed by Vayanos and Vila (2009) and Greenwood and Vayanos (2014), in which a shock to the net bond supply affects bond yields through both scarcity and duration risk. We add the spotlight effect to their framework to account for changes in the market perception of a particular bond immediately after the bond is included in the auction target and/or actually purchased. The scarcity effect gradually grows as the BoJ purchases more bonds and increases its share of bond holdings.

Our empirical analyses to identify an impact on liquidity comprise three parts. First, we examine the pattern of the term structure of the bid–ask spread, focusing on not only on-the-run but also off-the-run bonds, which are affected by spotlight effect more clearly. Second, we assess changes in the market depth of individual JGBs with Amihud’s (2002) illiquidity measure. Third, we conduct a threshold analysis on the BoJ’s holding ratio, which is a key variable for identifying any local scarcity effect. Our empirical methodologies are time-series analysis and cross-sectional analysis similar to the Fama–MacBeth procedures according to Friewald et al. (2012) and the threshold regression model in the spirit of Hansen (2000) and Pelizzon et al. (2016). In this paper, we provide empirical evidence of the spotlight and scarcity effects of the BOJ’s LSAPs, given an increase in the holding ratio at the individual security level.

Our paper makes three new contributions: One, it is the first, to our knowledge, to address explicitly the spotlight effect created by the LSAP. Two, it is the earliest study to investigate how the scarcity of net available bonds affects bond market illiquidity. As is intuitively reasonable, the greater the scarcity, the larger the bid–ask spread, which is the opposite of the findings of earlier studies, such as that of Iwatsubo and Taishi (2015) in the case of BoJ’s QE program, who report that the LSAPs actually *improve* liquidity because they do not include periods in which scarcity effects exceed the spotlight effect and they do not separate the scarcity effect from the spotlight effect. Three, we show that the market liquidity of the scarcity and spotlight effects has an impact on bond yields at the individual security level. We measure the different impacts of scarcity by looking at
the differential effects of the holding ratios of central banks. The BoJ’s LSAP increases scarcity in
some JGBs, which reduces the availability of bonds for the BoJ’s QE operation, especially if these
bonds do not have substitutable bonds. The objective of this analysis is to verify the presence of a
significant threshold in the BOJ’s holding ratio above which the relation between yield change and
time to maturity is altered.

The BoJ was the first major central bank to move aggressively toward introducing QE. Under the
BoJ Governor Haruhiko Kuroda, the bond purchase program approximately doubled to 50 trillion yen
(about 500 billion US dollars) per year in April 2013 and further increased to 80 trillion yen (about
800 billion US dollars) on October 2014. As a consequence of this massive purchase program, during
about three years (April 2013 to January 2016), the BoJ’s average holding ratio across JGBs jumped
from 10% to 37%, unprecedented in the annals of central bank history.

The BoJ conducted three distinct purchasing programs during our sample period from October
2010 to January 2016. The first program lasted from October 2010 to April 2013, under Bank
Governor Masaaki Shirakawa (the Shirakawa period hereafter). The latter two programs, from April
2013 to October 2014 (the QQE1 period) and from October 2014 to January 2016 (the QQE2 period),
were conducted with Governor Haruhiko Kuroda at the helm of the BoJ. These programs differ in
terms of the amounts of the purchases involved, as well as the maturities targeted, so that they
provide a natural experiment to determine how supply and maturity structure affect liquidity.

We first conduct a time-series analysis of market liquidity as proxied by changes in the bid–ask
spread. We measure daily changes in the bid–ask spread. We perform time-series analysis on changes in the
bid–ask spread to identify the spotlight effect associated with the program’s announcement, eligibility,
and actual purchase, with control variables for both global and domestic market conditions.

We find that a variable related to the spotlight effect is the program announcement, except for
our QQEX period (from February 28, 2013, to the end of May 2013). Inclusion in the target list
does not show a spotlight effect in the periods after introducing QQE. The list of target bonds that
the BoJ announces for each auction includes more than 90% of the existing bonds in the targeted
maturity bucket, but only one-third of the bonds in the target list are eventually purchased. Hence,
there is a large degree of uncertainty about which bonds will, in fact, be purchased.

The results of cross-sectional analyses identify a spotlight effect associated with actual purchase
upon operation and in the latest LSAP operation throughout the QE periods. With regard to the
scarcity effect, in QQE1 and QQE2, both the relative holding ratio of a bond and of its substitutable
bonds have a deteriorating effect on liquidity. The more of a bond the BoJ holds, the larger the
bond’s bid–ask spread. The holding ratio of a bond’s substitutes has a greater impact on illiquidity
than that of the bond itself. The BoJ purchased a wide array of bonds and increased its ownership
ratio so that scarcity increased the illiquidity of the bonds.

We confirm that the spotlight effect from the LSAP improves liquidity by narrowing the bid–ask
spread, but scarcity measured by the BoJ’s high holding ratio leads to a deterioration of liquidity in
the latter QQE programs.

We then analyze the effects of the LSAP on market depth, which measures the quantity available
for QE operations. Since the BoJ purchases bonds with special cautious on price, when the available
quantity of a particular bond for reverse auction is limited, it adjusts the purchase amount of the bond

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1 The size of the JGB trading volume was 25 trillion yen to 30 trillion yen per day during our sample period and
the US Treasury trading volume was about 55 trillion yen (500 billion US dollars) per day. The size of the JGBs was
about half that of the US Treasury.
according to the price impact caused by the BoJ purchase. Therefore, the market depth condition for an individual bond can be evaluated by Amihud’s (2002) illiquidity measure. To measure the yield change that occurs due to the BoJ’s operation, we run the first-stage regression with variables unrelated to the BoJ’s purchasing actions, such as bond characteristics, new bond issuance, and both global and domestic market conditions such as returns on the Japanese stock market and the US and German government bonds markets. In the second-stage regression, we compute Amihud’s illiquidity measure (ILLIQ) using the residual of the first-stage regression and regress the variables related to the spotlight and scarcity effects with ILLIQ. According to estimated coefficients of the period dummy variables, ILLIQ on QE0 is smallest and those in QQE1 and QQE2 are larger than those on QEbase and QE0. This means the depth of the JGBs was improved in QE0 due to a spotlight effect, while, after the introduction of QQE, the market depth worsened. Bonds that belong to the highest quintile of the substitutes’ holding ratio, however, show less depth. The lack of depth is more severe in QQE2 than that in QQE1.

Given the dramatic increase in the average holding ratio of the JGBs, the BoJ increased from 10% to 37%, in aggregate terms, in less than three years between April 2013 and January 2016. Next, we conduct a threshold analysis of the BOJ’s holding ratio, which is a key variable for identifying any individual scarcity effect. We expect the spotlight effect to dominate the effect of scarcity on yield change at an earlier stage; however, once the BOJ’s level of ownership reaches a certain level, the illiquidity of a bond due to high scarcity exceeds the spotlight effect. Increasing the BoJ’s JGB holdings increases the difficulty of market making. It is important to confirm whether the sensitivity of the remaining maturity to yield changes also shifts as a consequence. We statistically test for the presence of such a threshold.

In the case of bonds with a remaining maturity of one to 10 years, we find a statistically significant change in the yield sensitivity above a holding ratio of 59% and, in the case of bonds with maturity longer than 10 years, above 37%. A lower threshold for bonds with a maturity longer than 10 years reflects the lesser availability of substitutable bonds. The results indicate that the BOJ’s purchase program increases the market impact once its holding ratio exceeds the threshold. This indicates that illiquidity in the bonds’ secondary market worsens, which leads to a deterioration in the performance of fixed income portfolios managed by investors such as pension funds and by mutual funds. In fact, our results suggest that the aggressive QE conducted by the central bank increases the cost of investment in JGBs for pension funds and mutual funds, in terms of both bond yields as well as market liquidity. Not only does QE lead to lower yields but also the illiquidity cost of government bond transactions hurts the performance of fixed income portfolios and creates a significant cost transfer from the government to private investors.

The remainder of this paper is organized as follows. The next section reviews the literature. Section 3 reports a short history of the BOJ’s LSAPs. Section 4 describes the hypotheses and Section 5 presents the data and descriptive statistics. Section 6 reports the results of our empirical studies on market liquidity, as well as the non-linear impact of illiquidity due to scarcity on yield change, via the threshold analysis on the BoJ’s holding ratio. Section 7 concludes the paper.
2 Literature

2.1 Term Structure of Liquidity

The liquidity of fixed income securities focuses on particular maturities or the distinction between on- and off-the-run bonds. Goyenko et al. (2011) analyze the term structure of bond market liquidity and its relation with expected bond returns. They find that the difference in liquidity between long- and short-term bonds measured by bid–ask spreads increases during recessions. A similar analysis is provided by Schuster and Uhrig-Homburg (2012).

The liquidity premium has been attributed to the yield difference between equivalent securities with different levels of liquidity. Amihud and Mendelson (1991) find a significant yield differential between T-notes and T-bills with the same time to maturity. This evidence indicates that liquidity differences affect bond pricing. Krishnamurthy (2002) studies the price difference between on-the-run and the most recent off-the-run 30-year bonds and the results from the demand for liquid assets.

2.2 Channels

According to Vayanos and Vila (2009) and D’Amico et al. (2012), LSAPs can affect longer-term interest rates through three channels. The first channel is due to scarcity, or the local supply channel: The central bank’s purchase of assets with a specific maturity leads to higher prices of securities with similar maturities. The second channel is through duration risk: The central bank’s purchase of long-term securities reduces the duration risk in the hands of investors and thus lowers long-term bond yields relative to short-term yields. The third channel is signaling, or the expectations channel, through which the central bank alerts the market of its future purchases.

Vayanos and Vila (2009) develop a model in which a supply shock affecting the bond yields influences the behavior of risk-averse arbitrageurs. Their model implies an effect of the central bank’s purchasing program on the term structure of interest rates: When a central bank purchases bonds with specific maturities, it creates a supply shock to the market and the yield changes through the carry trade of arbitrageurs.

Bond prices also reflect a local scarcity factor associated with the premium for particular bond issues. The local scarcity channel implies that a change in the supply of bonds in a specific sector or of a certain maturity can differentially affect the yields of those bonds and bonds with similar but not identical characteristics.

Empirical studies based on Vayanos and Vila’s (2009) framework have been carried out by Greenwood and Vayanos (2010), D’Amico et al. (2012), and D’Amico and King (2013), for example. Greenwood and Vayanos (2014) empirically examine how the supply and maturity structure of government debt affect bonds’ yields and expected returns.

To evaluate the effect of purchases by the Fed, Cahill et al. (2013) measure the impact on the Treasury yields of five Federal Open Market Committee announcements of the Treasury purchase program. They focus on both the duration risk premium and local supply effects on the yield on the day of the program announcement and the next day and conduct a comparative study of the five programs using intraday CUSIP-level data. Song and Zhu (2016) also use intraday CUSIP-level data to measure the Fed’s cost for each auction. They define the cost as the price difference between the auction offer and the secondary market and propose three factors that affect the Fed’s cost. However, none of these papers investigates the scarcity effect on liquidity.
2.3 Scarcity

A paper that is more closely related to ours in terms of the scarcity effect is that of Blattner and Joyce (2016), who examine how shocks to the net supply of government bonds affect the term structure of interest rates and the macroeconomy. They use a free-float measure to quantify the net debt supply and report that the European Central Bank’s (ECB) government bond purchases reduced the 10-year bond yield by 30 basis points (bps) in 2015. The authors measure the scarcity created by foreign official institutions that constitutes a third of the total outstanding German central government debt. Our paper differs from theirs because we address scarcity created by the central bank itself, with a holding ratio as high as 86.3% (13.7% constitutes scarcity) of the outstanding debt. Time-series and cross-sectional observations allow us to identify the impact and threshold of the relation between scarcity and yield changes.

Another closely related paper on the scarcity issue is that of Joyce and Tong (2012), who investigate the impact of the Bank of England’s QE program during 2009–2010 on the UK government bond (gilt) yield. Using high-frequency securities-level data, they examine the yield change around the program announcement date and that around each reverse auction to capture the effect through the local supply channel and duration risk channel, showing that the bank’s QE purchases had a significant and persistent impact on yields. Although they include the bank’s holding amounts in their explanatory variables for reverse auction analysis, they do not apply the threshold model that we use in this paper. D’Amico et al. (2015) quantify the scarcity value of Treasury collateral by estimating the impact of security-specific demand and supply factors on the repo market. They find the amount purchased through the Fed’s operations has a negative and significant impact for on- and off-the-run securities.

2.4 Spotlight Effect

Spotlight effects are created in a situation in which a significant demand/supply imbalance is expected to take place through events. Such events include the inclusion/exclusion of major stock indexes (Harris and Gruel 1986, Beneish and Gardner 1995, Beneish and Whaley 1996). Those examine price pressure and the imperfect substitution hypothesis by means of the stock price and volume effects associated with changes in the composition of the Dow Jones Industrial Average and the Standard & Poor’s (S&P) 500 index. The event stimulates trading activity so that spreads decrease with trading volumes (Stoll 1978, Copeland and Galai 1983, McInish and Wood 1992). Beneish and Gardner (1995) find that firms are less widely followed after delisting from the Dow Jones Industrial Average. Beneish and Whaley (1996) find that the practice of announcements altered the way stock prices react when the S&P began its practice of preannouncing changes five days beforehand.

The central bank’s LSAP has a feature in common with the index event: It creates a rare trading opportunity. However, there are unique differences as well. In the case of an S&P 500 event, the replacement of constituents happens unexpectedly. Replacement is necessary when a constituent goes bankrupt, a company is newly listed or delisted due to a merger and acquisition, and so forth. The demand for a new entry is easily calculated based on the outstanding amount of index-linked assets and the timing of an index fund purchase is well known to be the day before the change. This situation allows dealers and speculators to create a position prior to index fund action and price pressure begins before actual demand from index funds.

There is one important difference between index and LASP events: The targeted securities and
auction schedule are not announced in advance. Furthermore, the central bank announces a bundle of bonds interested in purchase, but there are always many alternatives on the target list, so market participants need to conduct some guesswork to narrow down which bond the central bank will buy.

2.5 Bank of Japan’s QE

Lam (2011), Ueda (2013), Rogers et al. (2014), Fukunaga et al. (2015), and Iwatsubo and Taishi (2015), for example, have investigated the BoJ’s unconventional monetary policy. Lam (2011) uses an event study approach to investigate the impact of the BoJ’s monetary easing measures on the Japanese financial market. The author finds that the easing measures from December 2008 to August 2011 had a statistically significant impact on lowering bond yields. Ueda (2013) focuses on political pressure on the BoJ and the differences in behavior between foreign and domestic investors. Fukunaga et al. (2015) examine the effects of changes in bondholders and the remaining maturity on the term structure of interest rates. They are interested in the change in the term premium of JGBs and consider that preferred habitat investors include not only the BoJ but also long-term investors, such as pension funds and insurance companies. Iwatsubo and Taishi (2015) investigate the effect of the BoJ’s purchasing policy changes on market liquidity. They find that an increase in purchasing frequency, a decrease in the purchase amount per operation, and uniform purchase amounts improved market liquidity when QQE was introduced in 2013. These results contradict our analysis, because they do not look into QQE2, when scarcity effects increased. To our knowledge, no paper covers the recent aggressive LSAPs conducted by the BoJ, which differ from the interventions of other central banks in terms of size and scope, particularly given that the effects change fundamentally when the central bank’s holdings substantially exceed normal levels.

3 Research Issues and Hypotheses

In this paper, we aim to investigate the impact of QE on market liquidity by looking at both the time series and the cross-sectional perspective. We first answer the general question of whether, on average, QE improves or reduces market liquidity. As already mentioned, QE has two opposing effects on the liquidity of JGBs: the scarcity effect, which results from the reduction in liquidity due to shrinkage in the available bonds in the market, and the spotlight effect, which causes, from a macro perspective, an immediate improvement in liquidity during QE implementation, from greater attention to the JGB market in general.

**Hypothesis 1** The spotlight effect at the macro level is greater than the scarcity effect, therefore, QE, on average, induces an increase of liquidity.

In addition to the macro perspective, we aim to investigate at the micro level the impact of the spotlight effect and the scarcity effect. From a micro perspective, there should also be a cross-sectional effect, given that the BoJ buys different bonds throughout time; therefore, there is a spotlight effect drawing attention to individual bonds selected by the central bank. The inclusion of an individual JGB in the list of candidates for LSAP elicits keen attention from bond dealers and other market participants; thus, the spotlight effect has an immediate impact on bond liquidity. On the other hand, the scarcity effect is only gradually manifested as a negative impact on liquidity. Since the LSAP program involved the repeated purchase of significant amounts of individual securities, it is important to disentangle these two effects at the micro level.
We investigate the spotlight effect by looking at the fact that both inclusion in the target list and actual purchase by the BoJ induce market participants’ greater awareness of a trading opportunity. The spotlight effect expects to improve the liquidity of bonds. Then we derive the following prediction of the spotlight effect on liquidity. Since the list of target bonds that the BoJ announces for each auction includes more than 90% of the existing bonds in the targeted maturity bucket but only one-third of the bonds in the target list are eventually purchased, the BoJ purchase has a larger effect on liquidity than inclusion in the list does.

**Hypothesis 2** Liquidity is higher on reverse-auction days because bond spotlight effects, captured by inclusion in the target list or the actual purchase of a particular bond, decrease the bid–ask spread.

Next, we distinguish between on- and off-the-run bonds. The spotlight effect has a larger impact on off-the-run bonds than on on-the-run bonds, since the latter have better liquidity.

**Hypothesis 3** The spotlight effect on off-the-run bonds is greater than that on on-the-run bonds.

Lastly, we consider the effect through the scarcity (local supply) channel. Following the preferred habitat approach of Modigliani and Sutch (1966), we assume that the scarcity effect is mainly due to preferred habitat investors. Since referred habitat investors demand only those bonds with their preferred maturity, local scarcity causes bond prices to soar through demand and supply factors. We then derive the following prediction of the effect of LSAPs on liquidity through the scarcity channel.

**Hypothesis 4** The scarcity of bonds widens the bid–ask spread. If a number of bonds exist within a maturity bucket, those with smaller tradable amounts tend to have a wider spread.

## 4 LSAPs in Japan

### 4.1 Summary of Recent Purchase Programs

Since 2009, the BoJ has announced four major monetary programs. On October 28, 2010, the central bank announced a new asset purchase program of 35 trillion yen with the objective of decreasing longer-term interest rates. In this program, the BoJ conducted reverse auctions of financial assets up to 5 trillion yen per month, including about 1.5 trillion yen in JGBs. After that, the BoJ gradually increased the program’s total purchase amount and, toward the end of the program, the monthly purchase amount.

Kuroda’s nomination as governor of the BoJ (February 28, 2013) stimulated market speculation about expansion of the aggressive monetary easing. On April 4, 2013, the BoJ announced the introduction of QQE. It increased its purchases of JGBs to an annual amount of about 50 trillion yen. In particular, the BoJ also increased its reverse auctions of longer-dated JGBs and announced its intention to extend the average remaining maturity of its JGB purchases to seven years, up from three years. On October 31, 2014, the BoJ announced the expansion of the QQE such that the purchase amount would increase at an annual pace of about 80 trillion yen, approximately 30 trillion yen more than the previous amount, thus aiming to decrease interest rates across the entire yield curve. The BoJ announced that it was shifting its purchases further toward longer-term bonds to extend the average remaining maturity of purchases to about seven to 10 years. On January 29, 2016,
the BoJ introduced QQE with a negative interest rate. In this announcement, the BoJ revealed its policy of targeting a negative interest rate and of continuing to purchase JGBs in amounts increasing by about 80 trillion yen annually. The average remaining maturity of the BoJ’s JGB purchases thus rose to 12 years. As explained above, the BoJ accelerated its LSAPs several times after 2009. 

In this paper, we examine the effects caused by QQE by separating into five subperiods, as follows:

<table>
<thead>
<tr>
<th>Period</th>
<th>Start Date</th>
<th>End Date</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>QEbase</td>
<td>6/1/2011</td>
<td>1/31/2012</td>
<td>eight months</td>
</tr>
<tr>
<td>QE0</td>
<td>2/1/2012</td>
<td>2/27/2013</td>
<td>13 months</td>
</tr>
<tr>
<td>QQEX</td>
<td>2/28/2013</td>
<td>5/31/2013</td>
<td>three months</td>
</tr>
<tr>
<td>QQE1</td>
<td>6/1/2013</td>
<td>10/30/2014</td>
<td>17 months</td>
</tr>
<tr>
<td>QQE2</td>
<td>10/31/2014</td>
<td>1/28/2016</td>
<td>15 months</td>
</tr>
</tbody>
</table>

We designate June 1, 2011, to January 31, 2012 (eight months) as the calm period, because (1) the size of the BoJ’s intervention was small and stable and (2) its holding ratio remained around 13% of outstanding JGBs. In QE0, the BoJ gradually increased the purchase amount of JGBs. We then have the QQEX period between the QE0 and QQE1 periods (February 28, 2013, through May 31, 2013), when Kuroda was announced as the new governor and market participants were filled with uncertainty about how the new monetary policy would be implemented. Figure 1 shows the historical yield of JGBs with remaining maturities of one, five, 10, and 30 years.

As shown in Figure 1, a large fluctuation is observed on the announcement day introducing QQE on April 4, 2013. However, we are more concerned with the two months around the announcement of QQE. After around February 2013, the yield began to decline rapidly, which coincided with the timing of Kuroda’s nomination as governor of the BoJ. Upon Kuroda’s nomination, market participants might have expected the BoJ’s expansion of intervention in the JGB market. A reaction to the sharp decline was observed after the announcement. The volatility of JGB prices was also high in this period. Our empirical analyses in the following sections treat this period as a special period (QQEX).

Figure 2 shows the amounts (in trillions of yen) of nominal JGBs purchased monthly by the BoJ.

As shown in Figure 2, the BoJ gradually increased its holdings of JGBs after February 2012 but then rapidly increased them after the QQE announcement in April 2013. Most of the purchases in the first QQE period (QQE1) consisted of securities with maturities of one to 10 years. After expansion of the QQE, in the second QQE period (QQE2), the monthly purchase amounts increased, particularly for bonds with maturities of more than 10 years.

Tables 1a to 1c display the number of operations, the total purchase amounts, and the average auction sizes for the five periods, respectively.

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2According to the BoJ’s LSAP program history, we can define three periods, listed as follows:

<table>
<thead>
<tr>
<th>Period</th>
<th>Start Date</th>
<th>End Date</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>QE</td>
<td>10/28/2010</td>
<td>4/3/2013</td>
<td>29 months</td>
</tr>
<tr>
<td>QQE1</td>
<td>4/4/2013</td>
<td>10/30/2014</td>
<td>19 months</td>
</tr>
<tr>
<td>QQE2</td>
<td>10/31/2014</td>
<td>1/28/2016</td>
<td>15 months</td>
</tr>
</tbody>
</table>
Although the total purchase amount in each period dramatically increased after the introduction of QQE (QQE1 and QQE2), the amounts purchased in each auction did not increase much but the auction frequency did. A breakdown by remaining maturities reveals that both the auction frequency and the total amount decreased for shorter-term bonds, but the frequency increased greatly while the size increased relatively slowly for bonds with a maturity of over one year. This indicates that the BoJ had been trying to proceed with huge amounts of purchases while minimizing the influence of each purchase on the market.

[Figure 3 about here.]

Figure 3 shows the BoJ purchase amounts split between fresh and non-fresh bonds. Fresh bonds are defined as those less than one year from issuance. There is clear trend that the BoJ increasingly purchases fresh bonds in QQE1 and QQE2 compared with QE0 and earlier periods. We will quantify the determinants of the BoJ’s purchase behavior in Section 4.3

4.2 Reverse Auctions

We now describe the timeline of the BoJ’s reverse auctions. When the BoJ purchases JGBs, it conducts an auction through its financial network system (BOJ-NET) according to the following schedule:

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<thead>
<tr>
<th>Time</th>
<th>Auction</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:10</td>
<td>Offer to auction participants</td>
</tr>
<tr>
<td>11:40</td>
<td>Bid submission cutoff</td>
</tr>
<tr>
<td>Around 12:00</td>
<td>Notification of results</td>
</tr>
<tr>
<td>Two days later</td>
<td>Settlement</td>
</tr>
</tbody>
</table>

The BoJ proposes a purchase operation to the auction participants at 10:10 a.m. and announces the following through the BOJ-NET: (1) the total amount of the offer, (2) the issues to be purchased, (3) the purchase date, and (4) the bid submission cutoff date and time. These announcements cover not only the target issues but also any issues dropped from the purchases. After the BoJ executes an auction, it provides the results around 12:00 p.m.

4.3 The BoJ’s Purchasing Model

In this subsection, we look into the relation between the BoJ’s purchase behavior and its effects on liquidity. We estimate a Tobit model with variables that are likely to be determinants of the BoJ purchase.

Our sample periods include the five subperiods. We know from the BoJ’s announcement that, in the first three periods, the purchase are relatively small and the BoJ focuses on short-term bonds. In the latter two periods, the BoJ’s purchasing target shifts to longer-term bonds and its target list includes almost all existing bonds. We investigate five variables as the determinants of the BoJ’s purchase actions, such as the BoJ’s bond holding ratio, the yield curve fitting error, whether a bond was purchased in the previous auction, whether this was an on-the-run bonds, and time to maturity.

More formally, our regressions are performed with the following equation:
\[ \text{purchase}_{n,t} = \beta_0 + \beta_1 h_{n,t} + \beta_2 \text{svnerr}_{n,t-1} + \beta_3 \text{prevp}_{n,t} \\
+ \beta_4 \text{fresh}_{n,t} + \beta_5 \tau_{n,t} + \epsilon_{n,t} \]  

(1)

where \( h_{n,t} \) is the relative holding ratio of security \( n \), \( \text{svnerr}_{n,t-1} \) is the Svensson fitting error on the previous day, \( \text{prevp}_{n,t} \) is a dummy variable indicating whether the BoJ made a purchase in the previous auction, \( \text{fresh}_{n,t} \) is a dummy variable indicating whether the bond was issued within one year, and \( \tau_{n,t} \) is the remaining time to maturity.\(^4\) The dependent variable is the logarithm of the amount purchased by the BoJ. We run this model for the securities included in the target list.

[Table 2 about here.]

We estimate Eq. (1) by performing a panel censored regression of the maximum likelihood method using the Berndt–Hall–Hall–Hausman (1974) algorithm.

The results are shown in Table 2. In QQE1 and QQE2, the BoJ prefers to purchase fresh bonds (on-the-run bonds or bonds issued within one year). As we confirmed in Figure 3, this unique purchasing behavior is observed in the last three periods after the introduction of QQE. This tendency increases in QQE2 compared to QQE1. Similarly, the BoJ purchases a bond that it bought in the previous operation. This effect exists since the QE0 period. This behavior is important with respect to Hypothesis 4, which asks whether inclusion in the target list or actual purchase induces the spotlight effect. Throughout our estimation periods, the BoJ reduced its amount of purchase whenever the BoJ’s holding ratio of that bond was high. In QEbase period, the BoJ prefers to purchase underpriced bonds, but the fitting errors are not significant determinants in the last two QQEs. In summary, the BoJ purchases greater amounts if a bond was recently issued and the BOJ’s holding ratio of the bond is relatively small. In QQE2, the BOJ’s preference for fresh bonds strengthens, but the effect of its holding ratio slightly weakens.

5 Data and Descriptive Statistics

5.1 Liquidity Measures

Our data consist of daily observations in the universe of nominal coupon JGBs from February 2009 until January 2016.\(^5\) The daily price and best quote data at the end of each trading day are provided by Bloomberg.\(^6\) We use the last price, the bid price, and the ask price after June 2011 to investigate the LSAP’s effect in the next section and thereafter.\(^7\)

Among the liquidity measures examined in the literature, we use the bid–ask spread and Amihud’s illiquidity (ILLIQ) measure. The bid–ask spread can show one aspect of market liquidity that is

\(^3\)Since the holding ratio is calculated at a frequency that the BoJ discloses, \( h_{n,t} \) is the relative holding ratio using the information before time \( t \).

\(^4\)We define these variables in the next section.

\(^5\)Inflation-linked bonds are excluded from our sample.

\(^6\)We exclude data points when the Japanese market is not open from our sample. We also exclude bonds with fewer than 90 days to redemption because the yield to maturity increases as the redemption date approaches.

\(^7\)We inspect the data before May 2011, which are qualitatively different from the data after June 2011, because Bloomberg started incorporating quotes posted to the Bloomberg Electric Trading Platform around May 2011. We decided to use only the data after June 2011.
meaningful only for small lot orders. It indicates how market makers (dealers) perceive liquidity conditions. The quotes reported by Bloomberg are not firm quotes, so that their sensitivity to market liquidity may be limited. We substitute this shortcoming by looking at ILLIQ measures.

We first analyze the bid–ask spread as a measure of liquidity. The percentage of the bid–ask spread of security $n$ at time $t$ is defined as

$$\text{sprd}_{n,t} = \frac{\text{ask} - \text{bid}}{\text{midprice}} \times 100$$  \hspace{1cm} (2)

where \text{midprice} is the average of the ask and bid prices. We compute the bid–ask spreads of individual securities.

Next, to evaluate the spotlight and scarcity effects on market depth, we calculate ILLIQ using the BOJ’s purchase amount and its associated yield change. This indicates the market impact caused by a specific purchase amount, which allows us to speculate on market depth conditions. First, we regress market macro indicators on daily yield changes to exclude yield changes caused by factors unrelated to the BoJ’s purchase actions (we discuss the determinants of the BoJ’s purchase behavior in Section 4.3):

$$\Delta Y_{n,t,\Delta t} = \xi_0 + \sum_i \sum_k \xi_{ik} \text{Macro}^{k}_{n,t} \times \text{Cross}^i_{n,t} + \text{residual}_{n,t}$$  \hspace{1cm} (3)

where \(\Delta Y_{n,t,\Delta t}\) is the change in the yield to maturity of government bond $n$ from time $t - \Delta t$ to time $t$ and \{Macro$^k_{n,t}$\} includes domestic and global indicators such as \(ctopix_t\), \(cgbond_t\), and \(ccs_{n,t}\). \(\text{Cross}^i_{n,t}\) includes the dummy variables of the remaining time to maturity and \(ttm_{0-1y}^{n,t}\), \(ttm_{1-3y}^{n,t}\), \(ttm_{3-10y}^{n,t}\), and \(ttm_{10y+}^{n,t}\) are dummy variables that equal one when the remaining time to maturity of security $n$ is less than one year, between one and three years, between three and 10 years, and more than 10 years, respectively. Then, using the residuals of the regression of Eq. (3), we calculate the cumulative residuals only on those days when the BoJ made a purchase:

$$\text{cumres}_{n,s} = \sum_t \text{residual}_{n,t}$$  \hspace{1cm} (4)

Using the cumulative residual \(\text{cumres}_{n,s}\), our ILLIQ measure is calculated as

$$\text{ILLIQ}_{n,s} = \frac{\text{abs}(\text{cumres}_{n,s})}{\text{purchase}_{n,s}}$$  \hspace{1cm} (5)

where \(\text{abs}(\text{cumres}_{n,s})\) is the absolute value of \(\text{cumres}_{n,s}\) and \(\text{purchase}_{n,s}\) is the BoJ’s purchase amount from time $s - 1$ to $s$.

Figure 4 shows the liquidity term structure of JGBs based on the bid–ask spread for all the JGBs considered for six randomly selected days at about one-year intervals and Table 3 presents descriptive statistics of the bid–ask spreads. As the figure shows, the bid–ask spreads do present a time-to-maturity structure with a significantly positive slope. However, the bid–ask spread does not increase linearly with time to maturity with a certain concavity. The figure also shows significant dispersion of the bid–ask spread for bonds having the same time to maturity and this dispersion varies throughout time. Our analysis aims to capture both changes through time and the drivers of the cross-sectional dispersion due to the QE interventions.

---

8Later, we consider volume.
9We define these variables in the next three subsections.
The characteristics of each security, such as the issue date, the redemption date, and outstanding amounts, are publicly available on the Japanese MOF website. The amounts held by the BoJ are periodically announced on the BoJ’s website. The information announced for each reverse auction is collected from Reuters News and Nikkei Telecom.\(^\text{10}\)

5.2 Spotlight Variables

As described in Section 4.2, the BoJ announces an offer amount the morning of each operation day and the results are reported around noon. The BoJ notifies the auction participants whether the offer was successful.

To investigate the spotlight effect caused by a reverse auction announcement, we construct the following variables:

- \(\text{target}_{n,t}\) : Targeted bonds dummy that equals one when security \(n\) is targeted for the auction at time \(t\)
- \(\text{othera}_{n,t}\) : Dummy variable that equals one when security \(n\) is not included in the target list for the auction at time \(t\)
- \(\text{offer}_{n,t}\) : Logarithm of the amount offered for the auction at time \(t\)
- \(\text{drop}_{n,t}\) : Dropped bond dummy that equals one when security \(n\) is dropped for the auction at time \(t\)

Note that the \(\text{offer}_{n,t}\) variable is the logarithm of the amount offered in billions of Japanese yen (JPY).

We next consider the disclosure of the amount purchased by the BoJ. As mentioned, the BoJ does not disclose the details of the auction results until it discloses its holding amounts in a periodic disclosure.\(^\text{11}\) Since the auction participants know whether their offer is successful or not on the same day, this information spreads quickly among them. The information’s periodicity is longer than the period between two consecutive auctions. To examine whether the BoJ’s purchase of a certain bond has an effect on market liquidity, we set the following variables:

- \(\text{purchase}_{n,t}\) : Purchased amount of security \(n\) for the auction at time \(t\)
- \(\text{prevp}_{n,t}\) : Dummy variable that equals one when security \(n\) is purchased at a previous auction

\(^{10}\)Other data are obtained as follows. The information about newly issued bonds is from the MOF. We also obtained the interest rate on a constant maturity basis, which is used to estimate our yield curve, from the MOF. In our empirical analysis, we employ several macroeconomic indicators to control for the effect of LSAPs. These are all obtained from Quick Astra Manager, an arm of the Nikkei. The JGB Volatility Index (VIX) is provided by Standard & Poor’s and the Japan Exchange Group. We obtain information on the Fed’s and ECB’s program announcements from their respective websites.

\(^{11}\)The BoJ periodically discloses its JGB holding amounts. Before May 2014, the announcement frequency was once a month and, since then, three times a month.
We calculate $purchase_{n,t}$ by the increments of amounts held by the BoJ.

The announcement of the LSAP program may have an immediate impact on the JGB market. Since we want to examine its impact, we further define

$$program_t : \text{Dummy variable on the day of the LSAP program announcement}$$

5.3 Scarcity Variables

We intend to investigate the impact the scarcity of a bond (or its substitutes) has on market liquidity. The BoJ’s LSAPs have a significant impact on the bond supply, as indicated by Figure 5, which plots the holding ratio of government bonds, defined as the total amount of the BoJ’s holdings divided by the total amount of outstanding JGBs.

As shown in Figure 5, the BoJ’s holding ratio was around 10% until mid-2012 but then sharply increased and reached around 37% in February 2016. We construct our scarcity variables for securities, defined as follows: The BoJ’s relative holdings of security $n$ at time $t$ as a percentage of outstanding securities is

$$h_{n,t} = \frac{H_{n,t}/O_{n,t}}{\sum_n H_{n,t}/\sum_n O_{n,t}}$$  \hspace{1cm} (6)

where $O_{n,t}$ is the outstanding amount of security $n$ and $H_{n,t}$ is the amount of security $n$ held by the BoJ at time $t$. According to Greenwood and Vayanos (2014), the local scarcity channel implies that a change in the supply of bonds in a specific sector or of a certain maturity can differentially affect those bonds and bonds with similar but not identical characteristics. We follow this reasoning for our investigation on the effect of scarcity on liquidity. We define the BoJ’s relative holding ratio of substitutes of security $n$ at time $t$ as

$$sh_{n,t} = \frac{sH_{n,t}/sO_{n,t}}{\sum_n H_{n,t}/\sum_n O_{n,t}}$$  \hspace{1cm} (7)

where $sO_{n,t}$ is defined as all bonds outstanding with remaining maturities between $u-1$ and $u+1$ years if the remaining maturity $\tau$ of security $n$ satisfies $u < \tau \leq u + 1$, with $u = 0, 1, \ldots, 40$. The BoJ’s holdings of substitute $sH_{n,t}$ are defined similarly. These variables indicate whether sufficient bonds exist in the market.

5.4 Other Variables

Economic conditions changed globally during the seven years of our sample period. We, therefore, include variables that measure the effects of macroeconomics and the new issuance of securities as controls for the other effects on yield. In particular, the European sovereign debt crisis of late 2009 and the ECB’s as well as the US central bank’s actions greatly influenced the Japanese bond market. We use the following variables to control for macroeconomic conditions: $ctopix_t$, the daily rate of change in the Tokyo Stock Price Index (TOPIX), which tracks all domestic companies of the exchange’s First Section; $cbund_t$, the daily change in the yield of the 10-year German government’s Bundeswertpapiere the previous day; $ctbond_t$, the daily change in the yield of a 10-year US Treasury bond the previous day; $cglbond_t$, the average of $cbund_t$ and $ctbond_t$; and $ccs_{n,t}$, the change in the
US dollar (USD)/JPY floating-for-floating cross-currency swap for security \( n \).\(^{12}\) We further define the change in the JGB VIX, \( cvix \). This index measures the implied volatility of JGBs using option prices on JGB futures, as provided by S&P and the Japan Exchange Group. This variable assesses the volatility of the JGB market, which could affect the bid–ask spread dealers indicate.

The variables \( feda^- \) and \( feda^+ \) are dummy variables, where \( feda^- (feda^+) \) equals one the day after the Fed announces its QE program and when the change in the 10-year US Treasury bond is negative (positive) that day. Similarly, \( ecba^- (ecba^+) \) equals one the day after the ECB announces its QE program and the change in the 10-year German government bond is negative (positive) that day.\(^{13}\) We adjust all the variables observed in Europe or the United States in consideration of time zone differences.

Reverse auctions and new issue auctions are not scheduled the same day. The market is aware that large amounts of new issues occur periodically and they therefore behave cautiously one day before and one day after the new issuance day. To measure the effects on outstanding JGBs, we use the following three variables: \( \text{preis}_{n,t} \), the logarithm of the offer amount of security \( n \) issued the previous day when its maturity is within two years of the newly issued bond’s maturity; \( \text{issue}_{n,t} \), the logarithm of the offer amount of security \( n \) issued the day when its maturity is within two years of the newly issued bond’s maturity; and \( \text{aftis}_{n,t} \), the logarithm of the offer amount of security \( n \) issued the next day when its maturity is within two years of the newly issued bond’s maturity.

On-the-run bonds are the most recently issued bonds of a particular maturity. Since on-the-run bonds are the most frequently traded and the most liquid, their yields tend to be a little less than those of their off-the-run counterparts and their bid–ask spreads tend to be narrower. To capture these effects, we define \( \text{fresh}_{n,t} \) as a dummy variable that equals one when the bond was issued within one year.

The BoJ is more likely to purchase securities that are underpriced in the market and this is supposed to be known by investors. Generally, underpriced securities tend to revert to some averaging level by practicing arbitrage. However, when a bond is targeted by the BoJ, investors may buy more of the underpriced securities and may even buy overpriced securities, which has an impact on the bond’s liquidity. To identify underpriced securities, we use Svensson’s (1995) model. Svensson’s fitting error \( \text{svnerr}_{n,t} \) of security \( n \) at time \( t \) is defined as:\(^{14}\)

\[
\text{svnerr}_{n,t} : \text{The difference between the observed yield of each security and the corresponding estimate from Svensson’s model}
\]

We also use the characteristics of bonds such as the bond coupon, \( \text{coupon}_n \); the logarithm of the outstanding amount of security \( n \), \( \lnO_{n,t} \); and 20-, 30-, and 40-year bond dummies, \( \text{above10y} \).

\(^{12}\)Using 12-month, 18-month, one-year, two-year, three-year, four-year, five-year, six-year, seven-year, eight-year, nine-year, 10-year, 12-year, 15-year, 20-year, 25-year, and 30-year interest rates, we interpolate the USD/JPY cross-currency basis swap by spline interpolation and estimate a value corresponding to the remaining maturity of security \( n \).

\(^{13}\)In particular, we evaluate the signs of \( feda \) and \( ecba \) by principal component analysis. When the first principal component of the yield change is negative (positive), we categorize the dummy variable as negative (positive).

\(^{14}\)Using interest rate data on a constant maturity basis published by the MOF, we minimize residual error squares to create a believable yield curve with the Nelson–Siegel–Svensson method. We then set Svensson’s fitting error \( \text{svnerr}_{n,t} \) as the difference between the observed yield of each security and the corresponding estimate of Svensson’s model.
6 Empirical Analysis

We conduct four empirical analyses of the impact of QE on the JGB market. The LSAPs conducted by the BoJ are repeated events, so that market participants learn the preferences of the BoJ’s purchases. We first test for overall liquidity improvement (Hypothesis 1). Then we investigate the other three hypotheses stated in Section 3, referring to the impact of QE on market liquidity in the following sections. In Sections 6.2 and 6.3, we use the bid–ask spread and Amihud’s illiquidity measure as proxies of liquidity, respectively. In Section 6.4, we investigate the existence of a market impact threshold with respect to the BoJ’s holding ratio.

6.1 Overall Impact of the QQE Periods on Liquidity

**Hypothesis 1** The spotlight effect at the macro level is greater than the scarcity level; therefore, the QE, on average, induces an increase in liquidity. Liquidity is also higher on reverse-auction days.

If the spotlight effect has an immediate impact on liquidity, the scarcity effect affects liquidity only gradually. We should find that an earlier QE program improves liquidity. We test Hypothesis 1 by comparing the average bid–ask spread period by period.

[Table 4 about here.]

Table 4 shows the results of a Welch two-sample $t$-test. Comparisons with the QEbase period confirm improvement of liquidity for all bonds except the three- to 10-year bucket in the QE0 period. The BoJ purchase in QE0 focuses on an average duration of three years, so that the results of the zero- to one-year, one- to three-year, and three- to 10-year buckets are consistent with Hypothesis 1. On the other hand, there is a reduction of the spread for bonds with a maturity longer than 10 years throughout four periods. This result is consistent with the BoJ shifting toward longer-maturity bonds in the latter QQEs, so a large reduction of the spread is caused by the spotlight effect, but the reduction in spread in QE0 is not related to the spotlight effect. In this comparison, we do not adjust market factors; other factors, such as the European financial crisis, have a diminishing influence on the liquidity of long-term bonds. We will repeat the test for Hypothesis 1 with the ILLIQ measure.

6.2 Time-Series and Cross-Sectional Analysis of the Bid–Ask Spread

6.2.1 Effects of Daily Changes in the Bid–Ask Spreads of the QQE Periods on Liquidity

**Hypothesis 2** Bond spotlight effects, captured by inclusion in the target list or the actual purchase of a particular bond, decrease the bid–ask spread.

Spotlight effects can be observed as a time-series change in liquidity. We next examine the time series of bid–ask spreads. As mentioned, the BoJ’s target list includes almost all existing bonds. Inclusion in the target list may not, however, be a sufficient reason for market participants to choose such a bond. We investigate whether inclusion in an auction target list or actual purchase tightens
the bid–ask spread. We consider the following regression model of change in spreads:

\[
\Delta \text{sprd}_{n,t-1} = \alpha + \sum_i \beta_i \text{Spotlight}^i_{n,t-1} + \sum_j \gamma_j \text{Lagged}^j_{n,t-1} + \sum_k \theta_k \text{Macro}^k_{n,t-1} \\
+ \sum_l \kappa_l \text{Newly}^l_{n,t} + \sum_m \lambda_m \text{Control}^m_{n,t} + \epsilon_{n,t}
\]

(8)

where \(\Delta \text{sprd}_{n,t-1}\) is the change in the bid–ask spread of security \(n\) from \(t-1\) to \(t\) and \(\{\text{Spotlight}^i_{n,t}\}\) includes variables for examining the spotlight effect, such as the target dummy \(\text{target}_{n,t}\); another auction dummy \(\text{othera}_{n,t}\); the logarithm of the amount purchased by the BoJ, \(\text{purchase}_{n,t}\); a dummy indicating whether the BoJ made a purchase in the previous auction, \(\text{prevp}_{n,t}\); and a program announcement date dummy, \(\text{program}_{t}\). We add two lagged variables, \(\{\text{Lagged}^j_{n,t-1}\}\), such as the change in the bid–ask spread, \(\Delta \text{sprd}_{n,t-1}\), and the change in yield, \(\Delta \text{Y}_{n,t-1,t-2}\). The term \(\{\text{Newly}^l_{n,t}\}\) includes \(\text{prais}_{n,t}\), \(\text{issue}_{n,t}\), and \(\text{aftis}_{n,t}\), which equals the logarithm of offered amount if the substitute bond is newly issued the previous day, the same day, or the following day, respectively. The variable \(\{\text{Macro}^k_{n,t}\}\) includes domestic and global indicators, such as \(\text{cstopix}_{t}\), \(\text{cglbond}_{t}\), \(\text{cvix}_{t}\), \(\text{feda}_{t}\), \(\text{feda}_{t+1}\), \(\text{ecba}_{t}\), and \(\text{ecba}_{t+1}\), and \(\{\text{Control}^m_{n,t}\}\) includes the remaining time to maturity \(\tau\), which characterizes the term structure. The variable \(\epsilon_{n,t}\) represents the error term.

[Table 5 about here.]

Table 5 presents the regression results of change in the bid–ask spread. We calculate the significance of the coefficients from cluster-robust standard errors. Four variables are related to the spotlight effect: \(\text{program}_{t}\), \(\text{target}_{n,t}\), \(\text{purchase}_{n,t}\), and \(\text{othera}_{n,t}\). Among these four, the program announcement for QQE2 shows the largest improvement in liquidity, which is a 2.85-bp reduction of the bid–ask spread. We also have a significant negative coefficient for QE0, \(-0.3198\). However, the impact of the QQEX announcement \(^{15}\) is significantly positive, at 1.15, which indicates the deterioration of liquidity due to surprising and unknown policy changes for the market participants. The intercept of the regression is positive, which indicates a slightly widening spread. Inclusion in the target list shows a spotlight effect that improves liquidity until QE0. The coefficients for \(\text{target}\) are estimated to have larger negative values than those for \(\text{othera}\), which means the spread of the target bonds tends to be narrower on auction days. The coefficients for \(\text{target}\) become positive or insignificant after QQE1, which is because most of the bonds belong to the targeted bucket. There is no more special effect. However, a significant negative effect is associated with the other auction dummy after QQE1 and a significant coefficient is also estimated for the amount purchased by the BoJ. This means that the spread is tightened not for the bonds in the target list but only for the bonds that were actually purchased.

6.2.2 Cross-Sectional Analysis of the Bid–Ask Spread

**Hypothesis 3** The spotlight effect on off-the-run bonds is larger than that on on-the-run bonds.

**Hypothesis 4** The scarcity of bonds widens the bid–ask spread. If a number of bonds exist within a maturity bucket, those with smaller tradable amounts tend to have a wider spread.

\(^{15}\)The announcement of the BoJ’s introduction of QQE
In this subsection, we perform a cross-sectional analysis of the bid–ask spread in terms of levels rather than changes. We examine whether the variables measuring the spotlight or scarcity effect can explain the cross-sectional differences in bid–ask spreads. The following regressions are performed:

\[
sprd_{n,t} = \alpha + \sum_i \beta_i \text{Spotlight}_{n,t}^i + \sum_j \gamma_j \text{Scarcity}_{n,t}^j + \sum_k \theta_k \text{Bond}_{n,t}^k + \sum_l \kappa_l \text{Control}_{n,t}^l + \epsilon_{n,t}
\]  

(9)

where \{\text{Spotlight}_{n,t}^i\} includes variables for examining the spotlight effect, such as a target dummy \text{target}_{n,t}; the logarithm of the amount purchased by the BoJ, \text{purchase}_{n,t}; and a dummy indicating whether the BoJ made a purchase in the previous auction, \text{prevp}_{n,t}. We add the interaction term of \text{purchase}_{n,t} \times \text{fresh}_{i,t} to test whether the impact of the BoJ’s purchase on the on-the-run bond spreads changes. The other auction dummy and the program announcement date dummy are excluded for regressing the time fixed effects model. The term \{\text{Scarcity}_{n,t}^j\} includes the BoJ’s relative holding ratio \text{h}_{n,t}, and the BoJ’s relative holding ratio of substitutes, \text{sh}_{n,t}. The term \{\text{Bond}_{n,t}^k\} includes a dummy indicating whether the bond was issued within one year, \text{fresh}_{i,t}; a dummy for a 10-year bond, \text{above}10y; a coupon; and the logarithm of the amount outstanding, \text{lnO}_{n,t}. The term \{\text{Control}_{n,t}^l\} includes the remaining time to maturity \tau and its square, which characterizes the term structure of the bid–ask spread. The variable \epsilon_{n,t} represents the error term.

We run this model based on the Fama–MacBeth procedure according to Friewald et al. (2012).

Table 6 presents the results for the cross-sectional regression of the bid–ask spread for the five periods based on the time fixed within regression of the Fama–MacBeth procedure. The dependent variable is the end-of-day spread in basis points and the regression equation is presented in Eq. (6).

Among the variables related to the spotlight effect, the amount purchased by the BoJ and a bond purchased in a previous auction have significantly negative coefficients. This is consistent with Hypothesis 1 (spotlight effect improves the liquidity of a bond). The target dummy has a significantly positive coefficient. As mentioned, in QQE1 and QQE2, the BoJ specified targets for nearly all the bonds in the bucket, so that spotlight effects are not captured. The market cares more about actual purchases than indications of targets. According to our empirical model of BoJ purchases (Section 4.3), the BoJ exhibits a tendency to buy the same bond repeatedly.

Two variables related to the scarcity effect are the relative holding ratio of a bond and that of its substitutes. In QQE1 and QQE2, both have significantly positive coefficients. The higher the holding ratio, the larger the bid–ask spread, as expected, which is consistent with Hypothesis 3. The holding ratios are also significantly positive in QE0 and QQEX; however, the substitutes’ holding ratios are significantly negative in QE0 and QQEX. It is questionable whether the holding ratio before the aggressive QQE1 and QQE2 ever reach the level of availability of bonds. This works to indicate the BoJ’s preferences, similar to the spotlight effect.

6.3 Analysis of Market Depth

We now focus on the level of market depth, which is another aspect of the dimensions of liquidity. Due to limited data availability in the JGB market, we estimate the depth effect using Amihud’s illiquidity measure (ILLIQ). From the central bank’s point of view, the relation between the amount
of the purchase and an associated price impact (incremental price change) must be considered. This cannot be captured by simple analysis of the daily changes in the yield or bid–ask spread. The variable ILLIQ provides a specific measurement of the price (yield) impact when the BoJ purchases 1 billion yen, for instance. If a bond is scarce, small purchase amounts could generate a large price impact so that ILLIQ increases.

To examine the effect of scarcity on individual bonds in the two QQE periods, we further define dummy variables for the top quintile of the relative holding ratio of a bond or its substitutes’ relative holding ratio, defined in Eqs. (6) and (7), respectively, taking into account non-linearity. The variable $qown_{1,n,s}$ is a dummy variable for the top quintile of the relative holding ratio, $qown_{2,n,s}$ is for the second quintile of the own relative holding ratio, $qsub_{1,n,s}$ is for the top quintile of the substitutes’ relative holding ratio, and $qsub_{2,n,s}$ is for the second quintile of the substitutes’ relative holding ratio. Our equations for examining the ILLIQ measure are of the form

$$ILLIQ_{n,s} = \alpha + \sum_i \beta_i Period_i^j + \sum_j \sum_k \gamma_{jk} Period_j^k * Quintile^k_{n,s} + \epsilon_{n,s}$$

(10)

where \{Quintile^k_{n,s}\} includes $qown_{1,n,s}$, $qown_{2,n,s}$, $qsub_{1,n,s}$, and $qsub_{2,n,s}$ and \{Period^j\} includes only the QQE1 and QQE2 dummies, while \{Period^j\} includes the QE0, QQEX, QQE1, and QQE2 dummies.

Table 7 presents the results of the cross-sectional regression for ILLIQ. According to the estimated coefficients of the period dummy variables that account for the macro effect of the spotlight effect (Hypothesis 1), ILLIQ in QE0 is smaller and its values in QQE1 and QQE2 are larger than in QEbase and QE0. This means the depth of JGBs was improved in QE0 due to the spotlight effect, while, after the introduction of QQE, the market depth gradually worsened. This evidence supports Hypothesis 1, which describes the time-series development of two opposing effects. With respect to the scarcity effect, bonds in the highest quintile of the substitutes’ holding ratio exhibit decreased depths. The shallowness becomes more severe in QQE2 than in QQE1. The scarcity measure based on substitutes’ bonds shows a significant positive relation with ILLIQ. The results are consistent with those of Greenwood and Vayanos (2010) and D’Amico and King (2013).

6.4 Threshold Analysis of the BoJ’s Holdings

6.4.1 Threshold Analysis

In this section, we focus on the BoJ’s holding ratio, which is a key variable for identifying a scarcity effect. We expect changes in yield to be explained by the purchase amounts, as well as the remaining maturity. We introduce a threshold dummy variable that depends on the BoJ’s holding ratio to investigate the relation between yield changes and the remaining maturity conditional on the level of the BoJ’s holding ratio.

We set the BoJ’s holding ratio $H_{n,t}/O_{n,t}$ as our threshold variable and define the dummy variable

$$d(\delta) = I \{ H_{n,t}/O_{n,t} > \delta \}$$

(11)

where $I\{\cdot\}$ is the indicator function.
Introducing the threshold dummy variable \( d(\delta) \), we set the following regression model of yield change:

\[
\Delta Y_{n,t+1} = \alpha + \nu_1 \tau_{n,t} + \nu_2 d(\delta) \tau_{n,t} + \nu_3 \tau_{n,t}^2 \\
+ \sum_i \beta_i Spotlight_{n,t}^i + \sum_j \gamma_j Lagged_{n,t-1}^j + \sum_k \theta_k Bond_{n,t}^k \\
+ \sum_l \kappa_l Macro_{n,t}^l + \sum_m \lambda_m Newly_{n,t}^m + \epsilon_{n,t}
\]

(12)

where \( \{Spotlight_{n,t}^i\} \) includes the logarithm of the offer amount, offer\(_{n,t} \), and a dropped dummy drop\(_{n,t} \), and \( \{Lagged_{n,t-1}^j\} \) includes the Svensson fitting error the previous day \( svnerr_{n,t-1} \). The variable \( \{Bond_{n,t}^k\} \) includes the outstanding amount \( O_{n,t} \); \( \{Macro_{n,t}^l\} \) includes domestic and global indicators such as \( ccs_{n,t} \), \( ctbox_{t} \), \( cbond_{t} \), \( cbond_{t} \), \( cvix_{t} \), \( feda_{t} \), \( feda_{t} \), \( ecba_{t} \), and \( ecba_{t} \); and \( \{Newly_{n,t}^m\} \) includes \( preis_{n,t} \) and \( aftis_{n,t} \), which equal the logarithm of the offered amount if the substitute bond was newly issued the previous day and the following day, respectively. The variable \( \epsilon_{n,t} \) represents the error term.

The coefficient of \( d(\delta) \tau_{n,t} \) represents the threshold effect, where a large percentage of the BoJ’s holdings have an impact on yield. We examine the significance of \( \nu_2 \) in Eq. (12) to test the hypothesis that the sensitivity of the yield changes with a specific threshold value of the BoJ’s holdings. To test the significance of the threshold \( \delta \) at intervals of 1% and without being affected by a small sample, we test only when the dummy subsample contains over 3% of the whole sample.

### 6.4.2 Results of Threshold Analysis

We examine the significance of \( \nu_2 \) in Eq. (12) to test the sensitivity of yield changes for a specific threshold value of the BoJ’s holdings. The dependent variable is the daily yield change and we test the sample on days when purchase operations are performed from June 1, 2013, to January 28, 2016, which constitutes the QQE1 and QQE2 periods.

Figure 6 shows the results of the threshold dummy variable analysis for bonds whose maturities are less than one year and between one and three years. Figure 7 shows the results for the subsamples of bonds with maturities of three to 10 years and greater than 10 years. The sequential \( p \)-values of the significance tests and the coefficient estimates are shown for the threshold \( \delta \) changes at intervals of 1%.

[Figure 6 about here.]

[Figure 7 about here.]

Table 8 presents the results for the regressions of the yield change when the coefficient of the threshold dummy is estimated to be significant for the first time. We conduct the regression on the subsample of bonds with remaining maturities between one and three years, between three and 10 years, and above 10 years.\(^{16}\)

[Table 8 about here.]

\(^{16}\) There is no significant coefficient estimate for the subsample of bonds with less than three years to maturity.
The results for short-term bonds (with maturities up to three years) in Figure 6 are opposite those for long-term bonds (with maturities longer than three years) in Figure 7.

For the two subsamples in Figure 6, the coefficients $\nu_2$ are estimated to be positive, except for a small $\delta$ for the subsample with maturities of one to three years. A $t$-test shows that the coefficients are intermittently positively different between holding ratios of 19% and 55% for the subsample with maturities of one to three years, where the $t$-test shows $\nu_2$ to be statistically significant. The result also indicates that there is no threshold for the subsample of bonds with maturities of less than one year.

The results for long-term bonds in Figure 7 show that, from a statistical point of view, the test indicates a change in sensitivity when the BoJ’s holding ratio increases above 59% for bonds with maturities of three to 10 years and above 37% for bonds with maturities over 10 years. The coefficients are negative for long-term bonds (dotted line in the bottom panels of Figure 7). The coefficients range from -0.0179 to -0.0133 for the subsample of bonds with maturities of three to 10 years and from -0.0083 to -0.0058 for the subsample of bonds with maturities over 10 years. Our evidence suggests that the relation between the yield and the remaining maturity changed when the amounts held by the BoJ exceeded a certain threshold value. The negative sensitivity of the yield increased by 16% for a BoJ holding ratio of 59% for bonds with maturities of three to 10 years. The negative sensitivity of the yield for bonds with maturities of more than 10 years changed from positive to negative. In our sample periods, the direction of the price response differs, depending on short- or long-term bonds. When bonds are scarcer in the market, the yield of short-term bonds rises after controlling for other effects.

7 Concluding Remarks

The LSAPs of the major central banks around the world simultaneously create scarcity in the assets they target and generate a spotlight effect. This scarcity can be viewed as a supply shock, which has been addressed by many, such as Greenwood and Vayanos (2010), D’Amico et al. (2012), and D’Amico and King (2013). We investigate how such a supply shock affects the market impact and liquidity in the JGB market and how the spotlight effect renews attention to bonds that are not actively traded but LSAPs create rare trading opportunities for eligible bonds in QE. This paper explicitly investigates both effects on liquidity. No paper has yet explored both effects together, as far as we know.

The LSAPs of the BoJ utilize a reverse auction method to purchase government bonds. The BoJ announces the overall contents of the LSAP, but the implementation details, such as the list of target bonds, are not disclosed in advance. After the BoJ expands the amount of money allocated to QQE, the list of eligible bonds includes almost every JGB. Our results suggest that dealers and investors pay attention to what the BoJ bought in the previous operation and how much it bought.

Another important effect is the scarcity effect, which gradually penetrates the market liquidity of bonds. The greater the scarcity, the more difficult the market making of a bond. We find a bond’s remaining maturity and level of scarcity has a non-linear impact on liquidity (market depth and market impact).

In October 2014, the BoJ engaged in a bond purchase program (LSAP), announced by Governor Kuroda in April 2013, with an annual amount of 50?trillion yen (about 500 billion US dollars), which was further increased to 80 trillion yen (about 800 billion US dollars). Due to the massive
purchasing program, during a period of about three years (April 2013 to January 2016), the BoJ’s average holding ratio of government bonds (JGBs) jumped from 10% to 37%. As far as we know, this is largest holding ratio any central bank has ever reached.

In our analysis of these reverse auctions, we confirm the existence of a spotlight effect that is associated with the program’s announcements and actual purchases, but not with inclusion in the target list. Through cross-sectional analysis utilizing the Fama–MacBeth approach, we find that the greater the scarcity, the larger the bid–ask spread. Scarcity measured by substitutable bonds shows a strong relation. We examine market depth by looking at Amihud’s illiquidity measure (ILLIQ). We find that bonds purchased at reverse auctions show lower ILLIQ values, indicating greater market depth, but bonds in the top quintile based on the BoJ’s holding ratio of substitutable bonds shows deterioration of depth. We further investigate the threshold of the sensitivity of the relation between bonds’ remaining maturity and yield changes. Bonds with three to 10 years remaining to maturity and over 10 years remaining have central bank holding ratio thresholds of 59% and 37%, respectively. Above these thresholds, sensitivity is amplified. This result means that bonds for which the central bank’s holding ratio is above the threshold become very difficult to trade.

These results suggest, therefore, that an aggressive QE program can eventually adversely affect the government bond market’s liquidity and that the execution of such an LSAP program requires caution. In fact, not only does QE lead to lower yields but also the illiquidity cost of government bond transactions hurts the performance of fixed income portfolios and incurs a significant cost transfer from the government to private investors.

References


Figure 1: Historical yield of JGBs.
The time-series evolution of the JGB yield with remaining maturities of one, five, 10, and 30 years, by order of color darkness. The data set was obtained from the Japanese Ministry of Finance (MOF) website and covers the period from February 1, 2009, to January 28, 2016. The QEbase period is from June 1, 2011, to January 31, 2012; the QE0 period is from February 1, 2012, to February 27, 2013; the QQEX period is from February 28, 2013, to May 31, 2013; the QQE1 period is from June 1, 2013, to October 30, 2014; and the QQE2 period is from October 31, 2014, to January 28, 2016.
Figure 2: The BoJ’s monthly purchase amounts of nominal JGBs (in trillions of yen). The orange, dotted gray, gray-striped, and yellow areas indicate the BoJ’s monthly purchase amounts of bonds with a remaining maturity of less than one year, between one and three years, between three and 10 years, and more than 10 years, respectively. We calculate these by the increments of the amounts held by the BoJ. Recall that our data consist of the amounts of all nominal JGBs held by the BoJ from February 2009 to January 2016.
Figure 3: The BoJ’s monthly purchase amounts of fresh/non-fresh bonds (in trillions of yen). The green- and white-striped area indicates the BoJ’s monthly purchase amounts of fresh bonds (bonds issued within one year) and the pale green area indicates those of non-fresh bonds. We calculate these by the increments of the amounts held by the BoJ. Our data consist of the amounts of all nominal JGBs held by the BoJ from February 2009 to January 2016.
Figure 4: Liquidity term structure of the bid–ask spread.
This figure shows the liquidity term structure of the bid–ask spread for all the JGBs for six randomly selected days at about one-year intervals. In each panel, three types of marks distinguish whether a bond’s BoJ holding ratio is higher than the average holding ratio at that time. The x’s indicate a bond is an on-the-run bond.
Figure 5: Outstanding amounts and the BoJ’s holding amounts of nominal JGBs (in trillions of yen). The blue bars are the monthly outstanding amounts of nominal JGBs. The orange, dotted gray, gray-striped, and yellow areas indicate the BoJ’s holdings of nominal bonds with maturities of less than one year, one to three years, three to 10 years, and more than 10 years, respectively. The green line is the BoJ’s holding ratio. Our data consist of all nominal JGBs outstanding from February 2009 to January 2016.
Figure 6: Threshold analysis of the yield change for bonds with less than three years to maturity. The dependent variable is the percentage of the daily yield change and the regression is presented in Eq. (12). The top two panels show the sequential $p$-values of the $t$ significance test of $\nu_2$ for different thresholds $\delta$. The horizontal line shows the threshold of 5%. The bottom two panels show the coefficient estimates of the threshold dummy variable $d(\delta)\tau_{nt}$ for different $\delta$ values. The coefficients that are significant at the 5% level are displayed with a dotted line. The left panels show the results for bonds whose maturities are less than one year and the right panels show the results for bonds whose maturities are between one and three years. The sample period is from June 1, 2013, to January 28, 2016. The test is executed only when the dummy subsample contains over 3% of the whole sample.
Figure 7: Threshold analysis of the yield change for bonds with more than three years to maturity. The dependent variable is the daily yield change and the regression is presented in Eq. (12). The top two panels show the sequential $p$-values of the $t$-tests of $\nu_2$ for the different $\delta$ thresholds. The horizontal line marks a threshold of 5%. The bottom two panels show the coefficient estimates of the threshold dummy variable $d(\delta)\tau_n,t$ for different $\delta$ values. The coefficients that are significant at the 5% level are displayed with a dotted line. The left panels show the results for bonds whose maturities are between three and 10 years and the results on the right are for bonds with maturities of more than 10 years. The sample period is from June 1, 2013, to January 28, 2016. The test is executed only when the dummy subsample contains over 3% of the whole sample.
Table 1. Summary of Large Scale Asset Purchases.

Panels (a) to (c) show the number of operations, total purchase amounts, and average auction sizes, respectively. In each panel, the target ranges for the auctions are less than one year, one to 10 years, and more than 10 years for the QEbase, QE0, and QQEX periods and less than one year, one to 10 years, and more than 10 years for the first and second QQE periods, respectively. The QEbase period is from June 1, 2011, to January 31, 2012; the QE0 period is from February 1, 2012, to February 27, 2013; the QQEX period is from February 28, 2013, to May 31, 2013; the QQE1 period is from June 1, 2013, to October 30, 2014; and the QQE2 period is from October 31, 2014, to January 28, 2016.
Table 2. BoJ’s purchasing model.
This table presents the results for the panel censored regression of the amount purchased by the BoJ. The dependent variable is the logarithm of the amount purchased by the BoJ and the regression equation is presented in Eq. (1). We run the regression for each subperiod. The sample consists of nominal JGBs in the target list for the purchase operation with remaining maturities of at least 90 days. The $t$-values are in parentheses. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***) levels. The total number of observations and the number of censored observations are shown at the bottom of the table.

<table>
<thead>
<tr>
<th></th>
<th>QEbase</th>
<th>QE0</th>
<th>QQEX</th>
<th>QQE1</th>
<th>QQE2</th>
</tr>
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<tbody>
<tr>
<td>Intercept</td>
<td>-0.3535</td>
<td>4.7829 ***</td>
<td>4.5517 ***</td>
<td>-0.5864 ***</td>
<td>-2.5521 ***</td>
</tr>
<tr>
<td></td>
<td>( -1.65 )</td>
<td>( 37.34 )</td>
<td>( 27.79 )</td>
<td>( -5.35 )</td>
<td>( -14.81 )</td>
</tr>
<tr>
<td>Relative holding ratio</td>
<td>-0.9055</td>
<td>-0.9044 ***</td>
<td>-0.6077 ***</td>
<td>-1.8241 ***</td>
<td>-1.4467 ***</td>
</tr>
<tr>
<td>Svensson fitting error</td>
<td>-0.1307 ***</td>
<td>0.0034</td>
<td>0.0520 ***</td>
<td>-0.0016</td>
<td>-0.0145</td>
</tr>
<tr>
<td></td>
<td>( -3.85 )</td>
<td>( 0.42 )</td>
<td>( 14.63 )</td>
<td>( -0.45 )</td>
<td>( -1.52 )</td>
</tr>
<tr>
<td>Purchased in the previous operation</td>
<td>-0.3997 ***</td>
<td>0.2238 ***</td>
<td>-1.5621 ***</td>
<td>1.7373 ***</td>
<td>1.4685 ***</td>
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<tr>
<td></td>
<td>( -4.15 )</td>
<td>( 3.82 )</td>
<td>( -14.67 )</td>
<td>52.18</td>
<td>( 20.15 )</td>
</tr>
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<td>Fresh bond dummy</td>
<td>-0.0830</td>
<td>-0.3890 ***</td>
<td>0.4141 *</td>
<td>2.6452 ***</td>
<td>3.7377 ***</td>
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<tr>
<td></td>
<td>( -0.31 )</td>
<td>( -3.57 )</td>
<td>( 2.44 )</td>
<td>( 33.01 )</td>
<td>( 34.77 )</td>
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<td>Remaining time to maturity</td>
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<td>-0.1365 ***</td>
<td>-0.0689 ***</td>
<td>0.0167</td>
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<tr>
<td></td>
<td>( -12.01 )</td>
<td>( -38.12 )</td>
<td>( -21.87 )</td>
<td>( -9.37 )</td>
<td>( 1.64 )</td>
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<table>
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<tr>
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<th>Total observations</th>
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<th>8391</th>
<th>2689</th>
<th>22799</th>
<th>20920</th>
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<td>3597</td>
<td>1223</td>
<td>7886</td>
<td>5630</td>
<td></td>
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<td>Log-likelihood</td>
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<td>-12421.5</td>
<td>-3930.2</td>
<td>-31264.6</td>
<td>-23607.8</td>
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Table 3. Descriptive statistics of the bid–ask spread.
This table shows the average, median, and standard deviation of the bid–ask spread (in basis points) for each remaining maturity. The QEbase period is from June 1, 2011, to January 31, 2012; the QE0 period is from February 1, 2012, to February 27, 2013; the QQEX period is from February 28, 2013, to May 31, 2013; the QQE1 period is from June 1, 2013, to October 30, 2014; and the QQE2 period is from October 31, 2014, to January 28, 2016.

<table>
<thead>
<tr>
<th>Period</th>
<th>0–1 year</th>
<th>1–3 years</th>
<th>3–10 years</th>
<th>10–years</th>
<th>All sample</th>
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<tr>
<td><strong>QEbase</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.965</td>
<td>2.616</td>
<td>8.986</td>
<td>28.420</td>
<td>15.250</td>
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<tr>
<td>Median</td>
<td>0.800</td>
<td>2.174</td>
<td>7.143</td>
<td>25.310</td>
<td>9.766</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.604</td>
<td>1.625</td>
<td>6.233</td>
<td>9.969</td>
<td>13.588</td>
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<tr>
<td>Observation</td>
<td>2924</td>
<td>8271</td>
<td>13212</td>
<td>17391</td>
<td>41798</td>
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<td><strong>QE0</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
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<td>2.206</td>
<td>10.160</td>
<td>21.240</td>
<td>12.610</td>
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<td>Median</td>
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<td>1.844</td>
<td>6.761</td>
<td>18.250</td>
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<tr>
<td>Std. Dev.</td>
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<td>1.550</td>
<td>9.561</td>
<td>8.319</td>
<td>11.059</td>
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<tr>
<td>Observation</td>
<td>6138</td>
<td>11973</td>
<td>23015</td>
<td>29311</td>
<td>70437</td>
</tr>
<tr>
<td><strong>QQEX</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.662</td>
<td>2.100</td>
<td>7.121</td>
<td>17.310</td>
<td>10.020</td>
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<tr>
<td>Median</td>
<td>0.600</td>
<td>1.852</td>
<td>6.620</td>
<td>15.070</td>
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<tr>
<td>Std. Dev.</td>
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<td>1.190</td>
<td>3.506</td>
<td>5.701</td>
<td>7.815</td>
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<tr>
<td>Observation</td>
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<td>2668</td>
<td>5553</td>
<td>7117</td>
<td>16901</td>
</tr>
<tr>
<td><strong>QQE1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.869</td>
<td>2.649</td>
<td>11.030</td>
<td>16.940</td>
<td>11.420</td>
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<tr>
<td>Median</td>
<td>0.693</td>
<td>1.899</td>
<td>7.207</td>
<td>14.720</td>
<td>10.010</td>
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<td>Std. Dev.</td>
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<td>2.966</td>
<td>9.776</td>
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<td>9.120</td>
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<tr>
<td>Observation</td>
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<td>15185</td>
<td>31546</td>
<td>39860</td>
<td>93709</td>
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<tr>
<td><strong>QQE2</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Average</td>
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<td>2.706</td>
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<td>Std. Dev.</td>
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<td>Observation</td>
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<td>13843</td>
<td>28031</td>
<td>33834</td>
<td>82143</td>
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Table 4. Differences in the bid-ask spreads for two sample periods.
This table shows the Welch two-sample t-test whose alternative hypothesis is that the true difference in means is not equal to zero. The differences in the bid-ask spreads for the two sample periods and the significance of the tests are shown in the table. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***) levels. The QEbase period is from June 1, 2011, to January 31, 2012; the QE0 period is from February 1, 2012, to February 27, 2013; the QQEX period is from February 28, 2013, to May 31, 2013; the QQE1 period is from June 1, 2013, to October 30, 2014; and the QQE2 period is from October 31, 2014, to January 28, 2016.

<table>
<thead>
<tr>
<th></th>
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<th>QQEX</th>
<th>QQE1</th>
<th>QQE2</th>
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<tr>
<td>0-1 y</td>
<td>-0.028 **</td>
<td>-0.304 ***</td>
<td>-0.096 ***</td>
<td>-0.020</td>
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<tr>
<td>1-3 y</td>
<td>-0.409 ***</td>
<td>-0.516 ***</td>
<td>0.033</td>
<td>0.090 ***</td>
</tr>
<tr>
<td>3-10 y</td>
<td>1.177 ***</td>
<td>-1.865 ***</td>
<td>2.048 ***</td>
<td>-0.702 ***</td>
</tr>
<tr>
<td>10 y-</td>
<td>-7.184 ***</td>
<td>-11.114 ***</td>
<td>-11.482 ***</td>
<td>-10.323 ***</td>
</tr>
<tr>
<td>0-1 y</td>
<td>QE0</td>
<td>-0.276 ***</td>
<td>-0.068 ***</td>
<td>0.008</td>
</tr>
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<td>1-3 y</td>
<td>-0.106 ***</td>
<td>0.443 ***</td>
<td>0.500 ***</td>
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</tr>
<tr>
<td>3-10 y</td>
<td>-3.042 ***</td>
<td>0.871 ***</td>
<td>-1.879 ***</td>
<td></td>
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<td>10 y-</td>
<td>-3.930 ***</td>
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<td></td>
<td>0.208 ***</td>
<td>0.284 ***</td>
</tr>
<tr>
<td>1-3 y</td>
<td></td>
<td>0.549 ***</td>
<td>0.606 ***</td>
<td></td>
</tr>
<tr>
<td>3-10 y</td>
<td></td>
<td>3.913 ***</td>
<td>1.163 ***</td>
<td></td>
</tr>
<tr>
<td>10 y-</td>
<td></td>
<td>-0.368 ***</td>
<td>0.792 ***</td>
<td></td>
</tr>
<tr>
<td>0-1 y</td>
<td>QQE1</td>
<td></td>
<td></td>
<td>0.076 ***</td>
</tr>
<tr>
<td>1-3 y</td>
<td></td>
<td></td>
<td></td>
<td>0.057 **</td>
</tr>
<tr>
<td>3-10 y</td>
<td></td>
<td></td>
<td></td>
<td>-2.750 ***</td>
</tr>
<tr>
<td>10 y-</td>
<td></td>
<td></td>
<td></td>
<td>1.159 ***</td>
</tr>
</tbody>
</table>
This table presents the results for the regression of the changes in the bid–ask spreads for the five subperiods. The dependent variable is the change in the daily bid–ask spread in basis points and the regression equation is presented in Eq. (8). The sample consists of nominal JGBs outstanding with remaining maturities of at least 90 days. The t-values are in parentheses and are calculated from cluster-robust standard errors. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***). levels.

<table>
<thead>
<tr>
<th>Spotlight</th>
<th>QEbase</th>
<th>QE0</th>
<th>QQEX</th>
<th>QE1</th>
<th>QQE2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>-0.4730 ***</td>
<td>-0.0599 *</td>
<td>0.2159 ***</td>
<td>0.0462 *</td>
<td>-0.0305</td>
</tr>
<tr>
<td>Other auction</td>
<td>-0.3531 ***</td>
<td>-0.0253</td>
<td>0.1043 ***</td>
<td>-0.0730 ***</td>
<td>-0.1244 ***</td>
</tr>
<tr>
<td>Amount purchased by the BoJ</td>
<td>0.0151 ***</td>
<td>0.0019 *</td>
<td>-0.0074</td>
<td>-0.0074</td>
<td>-0.0181 *</td>
</tr>
<tr>
<td>Program announcement</td>
<td>-0.1533</td>
<td>-0.0198</td>
<td>1.5003 ***</td>
<td>NA</td>
<td>-2.8527 ***</td>
</tr>
</tbody>
</table>

| Lagged | Change in yield lagged | -0.0759 *** | 0.0111 | -0.0135 ** | -0.0342 *** | -0.0032 |
| Change in spread lagged | -0.4983 *** | -0.0425 *** | -0.0483 ** | -0.0456 *** | -0.4735 *** |
| Macro | TOPIX change | -0.0023 | -0.0794 *** | 0.0574 *** | 0.0003 | 0.0916 *** |
| US and German bond change | -1.6109 *** | -1.4075 *** | -0.6135 | -0.6038 * | 1.6997 *** |
| JGB VIX change | 1.8991 *** | 0.0442 | -0.4790 *** | 0.1724 *** | 0.1644 *** |
| Fed announcement date (−) | -0.0083 | 0.1272 *** | 0.2083 *** | -0.0098 | -0.5953 *** |
| Fed announcement date (+) | -0.0606 | (2.84) | (4.29) | (0.16) | -0.03 |
| ECB announcement date (−) | -0.0617 *** | 0.9139 | -0.1087 * | -0.5438 *** | -0.0650 *** |
| ECB announcement date (+) | -1.431 | 0.3278 *** | -0.0535 | 0.1324 *** | -0.9357 *** |
| Newly issued (issue date) | 0.0506 * | 0.0143 | 0.0143 * | -0.0528 *** | 0.0004 |
| Newly issued (day before the issue) | 0.0054 | 0.0291 * | -0.0062 | 0.0002 | 0.0024 |
| Newly issued (day after the issue) | -0.0227 | -0.0715 *** | 0.0080 | 0.0269 ** | -0.0298 * |

| Control | Intercept | 0.1476 *** | -0.0072 | -0.1230 *** | 0.0295 *** | 0.0568 *** |
| Remaining time to maturity | -0.004 *** | -0.0062 *** | 0.003 | -0.001 *** | 0.001 *** |
| Observations | 41798 | 70437 | 16901 | 97709 | 82143 |
| Adjusted R squared | 0.256 | 0.198 | 0.237 | 0.209 | 0.227 |

Table 5. Pooled regression of the changes in the bid–ask spreads.
### Table 6. Cross-sectional regression of the bid–ask spread.

This table presents the results for the cross-sectional regression of the bid–ask spread based on the Fama–MacBeth procedure estimated for the five periods. The dependent variable is the daily bid–ask spread in basis points and the regression equation is presented in Eq. (9). The sample consists of nominal JGBs outstanding with remaining maturities of at least 90 days. The $t$-values are in parentheses and are calculated from cluster-robust standard errors. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***).
Table 7. Regression of Amihud’s illiquidity measure (ILLIQ). This table presents the results for the cross-sectional regression of ILLIQ. The dependent variable is ILLIQ, defined in Eq. (5), and the regression equation is presented in Eq. (10). The ILLIQ values are calculated at the frequency of the BoJ’s disclosure of its JGB holding amounts. The t-values are in parentheses and are calculated from robust standard errors. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***). levels.

<table>
<thead>
<tr>
<th></th>
<th>Cross term with QQE1</th>
<th>Cross term with QQE2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.637 ***</td>
<td>0.773 ***</td>
</tr>
<tr>
<td></td>
<td>( 9.3 )</td>
<td>( 11.3 )</td>
</tr>
<tr>
<td>QE0</td>
<td>-0.131 **</td>
<td>-0.108 **</td>
</tr>
<tr>
<td></td>
<td>( -1.97 )</td>
<td>( -1.61 )</td>
</tr>
<tr>
<td>QQEX</td>
<td>0.219 ***</td>
<td>0.274 ***</td>
</tr>
<tr>
<td></td>
<td>( 2.81 )</td>
<td>( 3.27 )</td>
</tr>
<tr>
<td>QE1</td>
<td>0.104 ***</td>
<td>0.097 **</td>
</tr>
<tr>
<td></td>
<td>( 1.4 )</td>
<td>( 1.27 )</td>
</tr>
<tr>
<td>QE2</td>
<td>0.070 *</td>
<td>0.072 *</td>
</tr>
<tr>
<td></td>
<td>( 1.0 )</td>
<td>( 0.72 )</td>
</tr>
<tr>
<td>Top quintile of holding ratio</td>
<td>0.084 (1.27)</td>
<td>0.239 (2.60)</td>
</tr>
<tr>
<td></td>
<td>( -0.373 )</td>
<td>( -4.04 )</td>
</tr>
<tr>
<td>Second quintile of holding ratio</td>
<td>0.046 (0.56)</td>
<td>-0.028 ( -0.27 )</td>
</tr>
<tr>
<td></td>
<td>( -0.135 )</td>
<td>( -1.42 )</td>
</tr>
<tr>
<td>Top quintile of substitutes’ holding</td>
<td>-0.268 ( -4.20)</td>
<td>0.340 (3.2)</td>
</tr>
<tr>
<td></td>
<td>0.590 ***</td>
<td>( 6.3 )</td>
</tr>
<tr>
<td>Second quintile of substitutes’ holding</td>
<td>-0.020 ( -0.16)</td>
<td>-0.220 ( -1.64)</td>
</tr>
<tr>
<td></td>
<td>-0.003 **</td>
<td>( -0.02 )</td>
</tr>
</tbody>
</table>

Observations 6584  
Adjusted R squared 0.0253
Table 8. The threshold regression model for yield change.

This table presents the results for the regressions of the yield change when the coefficient of the threshold dummy is estimated to be significant for the first time. The dependent variable is the daily yield change in basis points and the regression is presented in Eq. (12). The columns on the left show the results for bonds whose maturities are between one and three years for a threshold of \( \delta = 0.19 \). The center columns show the results for bonds whose maturities are between three and 10 years for a threshold of \( \delta = 0.59 \). The columns on the right show the results for bonds whose maturities are more than 10 years for a threshold of \( \delta = 0.37 \). The sample consists of nominal JGBs on days the operation is performed from June 1, 2013, to January 28, 2016. The \( t \)-values are in parentheses. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***) levels.