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Scarcity and Spotlight Effects on Liquidity and Yield: Quantitative Easing in Japan

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Abstract

We investigate the determinants of the term structures of market liquidity and bond yield in the case of the Quantitative Easing (QE) programs implemented by the Bank of Japan (BoJ). We distinguish between two opposing effects of QE on the liquidity of Japanese Government Bonds, the "scarcity effect," which is *gradually* manifested as a negative impact on liquidity, due to the shrinkage in the available supply of bonds; and the "spotlight effect," which induces an *immediate* improvement in liquidity, reflecting BOJ's massive demand. Between 2011 and 2016, we find that government bonds show an improvement in liquidity through the spotlight effect, but also experience a deterioration in liquidity through the scarcity effect. As for the yield, both the spotlight and scarcity effects work in the *same* direction (i.e., they raise bond prices) against theoretical expectation. Illiquidity caused by scarcity amplifies the yield decline rather than adding to the illiquidity premium.

Keywords: Sovereign Bonds; Quantitative Easing; Market Liquidity; Scarcity; Spotlight

JEL classification: C54, E43, E52, E58, G12, G14

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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 by purchasing several assets, including Japanese government bonds (JGBs), shares of real estate investment trusts, and even equity exchange-traded funds, with the objective of stimulating the economy through a reduction in interest rates. The BoJ's holding of JGBs reached 437 trillion yen in June 2017, which corresponds to about 81% of Japan's nominal gross domestic product, while its average holding ratio across JGBs jumped from 10% to 40.3% during this period, unprecedented in the annals of central bank history.[1] 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, the ability of market participants to buy and sell reasonable amounts of bonds with minimal price impact, which has not been fully explored.[2]

For the QE effect on bond yields, the 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, identifies two main channels, duration risk and scarcity channels. Among them, D'Amico and King (2013) calls scarcity effect as local–supply effect and they suppose that the LSAPs push down the yield through the scarcity (local–supply) effect because the US Federal Reserve System (Fed)'s asset purchases with a specific maturity leads to higher prices of securities with similar maturities. They also suppose the reduction of the yield though the duration effect because the removal of aggregate duration reduces term premiums on securities.

We argue that the LSAP has two opposing effects on the liquidity of government bonds, the "scarcity effect," which is gradually manifested as a negative impact on liquidity, due to the shrinkage in the available supply of bonds in the market; and the "spotlight effect," which induces an immediate improvement in liquidity, arising from the attention focused on individual bonds selected by an aggressive purchaser (the central bank). We assume each purchase operation provides trading opportunities and makes bond holders easy to sell their bonds to dealers. The demand from the BoJ increases the competition among dealers which leads to tightening the bid–ask spread. On the other hand, scarcity effect on liquidity increases the spread because market makers face larger risk of holding short position due to reduction of the float of bonds.

[1] The JGB trading volume was 25 trillion yen to 30 trillion yen per day during our sample period, while the US Treasury trading volume was about 55 trillion yen to 60 trillion yen (500 billion US dollars) per day. The amount outstanding in the JGB market was about half that of the US Treasury market.

[2] Iwatsubo and Taishi (2017) and Schlepper et al. (2017), among others, are exceptions.

Theoretically, higher illiquidity should be compensated by a higher liquidity premium (Amihud and Mendelson 1986, 1991). While the spotlight effect garners attention to particular bonds, their illiquidity is increased by aggressive purchases almost simultaneously. This liquidity change should, therefore, adversely affect the bond yield. This is the point the literature such as D'Amico and King (2013) does not look into. According to Amihud and Mendelson (1986), the positive effect of large-scale bond purchases by the central bank should be, at least partially, nullified by the negative effect through the decline of liquidity resulting from a reduction in the "free float" of these bonds, that is, the bonds available for trading in the market. Thus, the LSAP creates both a scarcity effect and a spotlight effect, which have opposing impacts on the entire term structure of bond yields and liquidity. Which of the two effects dominates is an open question that can only be addressed empirically, on both a bond-by-bond basis and a period-by-period basis, which is our central objective in this paper.

The BoJ was the first major central bank to move aggressively toward introducing QE, way back in 2001. This was accentuated after the global financial crisis, when the BoJ, along with other major global central banks, employed aggressive measures to stimulate the economy. These measures received further impetus in 2013, under BoJ governor Haruhiko Kuroda, when the bond purchase program was 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) since October 2014. These QE programs are implemented by an auction mechanism similar to that used by the Fed in its 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 across a broad range of bonds. Such an action creates unique trading opportunities for bonds on the target list for dealers and other investors. Hence, the inclusion of a bond, especially an off-the-run bond, in the BoJ's target list draws keen attention from bond dealers and investors, resulting in positive effects for bond prices and liquidity. Thus, the spotlight effect has an immediate impact on the price and liquidity of individual bonds in the term structure of government bonds and is conceptually different from the broad signaling effect of the QE announcement, because it is caused not only by the general policy intervention, but also by the interaction between the central bank actions and dealer reactions in each purchase operation. The BoJ conducted three distinct purchasing programs during our sample period from October 2010 to January 2016. The latter two programs, from April 2013 to October 2014 (period QQE1) and from October 2014 to January 2016 (period QQE2), differ in terms of the amounts of purchases involved, as well as the maturities targeted. For instance, our sample includes a bond for which the central bank's holding ratio was as high as 78.9% of the outstanding debt, which provides a natural experiment to determine how the supply and the maturity structure affect the liquidity term structure.

We conduct two different econometric analyses, similar to Friewald et al. (2012).[3] First, we conduct an analysis of market liquidity by performing a time-series analysis with bond fixed effects on daily changes in the bid–ask spreads (used as a proxy for liquidity) to identify the spotlight effect at a macro level with control variables for both global and domestic market conditions. We then perform a cross-sectional analysis with time fixed effects. Second, we investigate the impact of the BoJ's purchases on bond yields, using the same approach. The direction and degree of the impact on bond yields can be complicated by the tension between strong demand and the reduced free float of the bonds, which we investigate in detail.

We find that a key variable related to the spotlight effect on liquidity is the actual purchases in the previous purchase operation. Inclusion in the target list, however, does not show a clear spotlight effect on liquidity. 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 on the target list are eventually purchased. Hence, the inclusion of a bond on the target list does not have a special signal as a spotlight effect. The results of the cross-sectional analysis on liquidity identify a spotlight effect associated with the actual purchases in the latest LSAP operation.

With regard to the scarcity effect, the relative holding ratio of a bond has a deteriorating effect on liquidity throughout subsequent periods. The more of a bond the BoJ holds, the larger the bond's bid–ask spread. The holding ratio of a bond's substitutes also increases illiquidity in both QQE1 and QQE2. 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 holding ratio leads to a deterioration in liquidity in the latter Quantitative and Qualitative Easing (QQE) programs, leading to two opposing effects.

Next, we look at yield changes resulting from the operation and investigate their relation to the spotlight and scarcity effects. The spotlight effect arises from the strong demand for the broad range of JGBs. The yields of bonds on the target list as well as purchases in the previous operation, in fact, fall. We find that the spotlight effect increases the yield changes. In the cross-sectional analysis of yield, a variable for targeted bond is associated with lower yields and a variable that captures scarcity also pushes yield down (and prices up). According to Amihud and Mendelson (1991), the degree of illiquidity should be a discounting factor for the bond price. Our results suggest, however, that the

[3]Friewald et al. (2012) use Fama–MacBeth cross-sectional regressions, but we apply a time fixed model for cross-sectional analysis.

yield level is more influenced by demand factors induced by the LSAP than the illiquidity created by the purchases. The purpose of the LSAP is reduction of the interest rate and the central bank does not care about illiquidity of the bonds when it purchases them.

We further explore the change in the liquidity term structure by dividing our sample into three distinct life stage groups: "fresh," "old," and "shadow" bonds. The three groups have distinct factors determining their market liquidity. Our definition of new bonds consists of those whose age is less than one year. Shadow bonds are those with a residual time to maturity that corresponds to that of others with shorter original maturity in the market. The trading activity of shadow bonds decreases due to the existence of younger competing bonds. For example, a 10-year bond with a residual maturity of four years, since a five-year bond with a similar four-year residual maturity exists, would be classified as a shadow bonds. Bond life stages are a unique feature of bond liquidity, such that two four-year maturity bonds, one whose original maturity is 10 years and the other whose original maturity is five years, suffer a differential effect on their liquidity. Among bonds with the same maturity, the longer the original maturity, the greater the market making risk for bond dealers and the larger its potential price impact. Old bonds consist of those between fresh and shadow bonds. The opportunity created by the LSAP may affect bonds differentially depending on their life stage. Liquidity term structure analysis among the three groups reveals that the liquidity of the old bonds improves in QQE1 and QQE2 and becomes similar to that of fresh bonds but the liquidity of shadow bonds remains inferior to that of the others. In addition, when a bond was purchased in a previous operation, it exhibits better liquidity due to a subsequent purchase.

The analysis of the term structure of yields for three bond life stages shows that the own relative holding ratio lowers the yields of old and shadow bonds. In the case of fresh bonds, however, the own holding ratio of a bond has a positive impact on yield. Fresh bonds show the higher yield associated with the own holding ratio except QQE1, consistent with theoretical prediction of Amihud and Mendelson (1986). This is our unique finding in QQE impact on yield. However, substitutes holding ratio turns to negative in QQE1 and QQE2. These changes can be interpreted as when substitutes holding ratio is higher than the BoJ's average holding ratio, the yield change of this bond may be amplified due to lack of substitution. In total, the results on yields indicate that the spotlight effect is the dominant pricing factor for otherwise illiquid bonds.

Overall, our results suggest that the aggressive QE conducted by the central bank gradually increases the cost of investment in JGBs for pension funds and mutual funds in terms of both bond yields and market liquidity. Not only does QE lead to lower yields, but also it raises the illiquidity cost of government bond transactions.

Our paper makes three new contributions. First, it is the first, to our knowledge, to explicitly address the spotlight effect created by the LSAP. Second, it is the one of few to investigate how the scarcity of net available bonds affects bond market illiquidity.[4] Third, we explore the effects of the LSAPs on a bond-by-bond basis categorized by three bond life stages. This bond life stage concept is an essential element for understanding the differential effects on liquidity and yield caused by the LSAPs.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 presents a short history of the BoJ's LSAPs. Section 4 describes the hypotheses and Section 5 presents the data and descriptive statistics. Sections 6 and 7 report the results of our empirical estimations on market liquidity and bond yield, respectively. Section 8 concludes the paper.

2 Literature

2.1 Term Structure of Liquidity

The liquidity term structure shows the relation between the time to maturity and liquidity. In assessing liquidity, one may focus on particular maturities or on the distinction between on- and off-the-run bonds. Goyenko et al. (2011) analyze the term structure of bond market liquidity and its relation to 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 is 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 residual time to maturity. This evidence indicates that the liquidity differences affect bond pricing. By the time T-notes approach maturity, the notes have already been locked away in investors' portfolios and a large part of each issue is not readily available in the market. This "lock-in proportion" is, in fact, typically excluded from the free float of bonds. Krishnamurthy (2002) studies the price difference between on-the-run and the most recent off-the-run 30-year bonds and the results come 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

[4]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 (2017). In their study, the BoJ's LSAPs actually *improve* liquidity because the authors do not include periods in which the scarcity effects exceed the spotlight effect and their estimation does not separate between the scarcity and the spotlight effects.

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 due to 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 for 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. They 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 78.9% of the outstanding debt. Time-series and cross-sectional observations allow us to identify the impact 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 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. D'Amico et al. (2013) 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, as shown by Harris and Gurel (1986), Beneish and Gardner (1995), and Beneish and Whaley (1996). The studies 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, as for Stoll (1978), Copeland and Galai (1983), and 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, since the LSAP program indicates the central bank's commitment to purchase specified assets. However, there are unique aspects 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 the actual demand from index funds. In the case of a LSAP conducted by the BoJ, the schedule of LSAP operations is not disclosed. Furthermore, there is one important difference between the index and LSAP events. The targeted securities and auction schedule are not announced in advance. The central bank announces a bundle of bonds that it is interested in purchasing, but there are always many alternatives on the target list, so that market participants need to do some guesswork to narrow down which bond the central bank will ultimately buy.

2.5 BoJ's QE

Lam (2011), Ueda (2013), Rogers et al. (2014), Fukunaga et al. (2015), and Iwatsubo and Taishi (2017), 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 (2017) 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 at QQE2, when scarcity effects were accelerated. 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 and yield from both a time-series and a 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, due to greater attention to the JGB market in general.

Hypothesis 1 *Since the spotlight effect at the macro level is stronger than the scarcity effect, QE, on average, induces an improvement in liquidity.*

In addition to the macro perspective, we aim to investigate, at the micro level, the impact of the spotlight and scarcity effects. From a micro perspective, there should also be a cross-sectional effect, given that the BoJ buys different bonds over 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 involves 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 the record of purchase by the BoJ induce market participants' greater awareness of a trading opportunity. The spotlight effect is expected to improve bond liquidity. Since the list of target bonds that the BoJ announces for each auction includes more than 90% of the bonds in the targeted maturity bucket but only one-third of those on the target list are eventually purchased, we expect the BoJ purchase to have a larger effect on liquidity than inclusion in the list does. From this argument, we derive the following prediction of the spotlight effect on liquidity.

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

We next consider the effect on liquidity through the scarcity (local supply) channel. Following the preferred habitat approach of Modigliani and Sutch (1966), which assumes that the scarcity effect is mainly due to preferred habitat investors, one could conjecture that these investors demand only those bonds with their preferred maturity. Hence, local scarcity would cause these bond prices to soar through the shrinkage in supply due to the LSAPs. Our argument is somewhat different. We assume, instead, that the scarcity effect is mainly due to market making risk. The reduction of the float increases the possibility that dealers will be unable to close their short position by searching for the supply of a particular bond. Market makers raise the ask price to avoid the creation of such a forced short position. Based on this argument, we derive the following prediction for the effect of LSAPs on liquidity through the scarcity channel.

Hypothesis 3 *The scarcity of bonds increases illiquidity, which is accentuated when there is a scarcity of even substitutable bonds, such as those with similar maturity.*

Next, we introduce three bond life stages that distinguish between fresh, old, and shadow bonds. Under normal market conditions, the liquidity of fresh bonds is the highest, followed by that of old bonds, with the liquidity of shadow bonds being the lowest. The spotlight effect has the least impact on fresh bonds, since the market normally focuses on these bonds for trading, so the additional effect is minimal. For old bonds, the spotlight effect increases the opportunity to trade and, thus, improves the liquidity of old bonds. Compared to old bonds, shadow bonds should experience a similar impact from the spotlight effect, but creating a trading opportunity is more difficult, since they are likely to be locked away in long-term portfolios; thus, the spotlight effect on liquidity is different, depending on the bond life stage.

Hypothesis 4 (a) *The spotlight effect on the liquidity of old bonds is greater than that on the liquidity of fresh bonds.* (b) *The spotlight effect on the liquidity of shadow bonds is mitigated by their high illiquidity.*

Next, we aim to investigate at the micro level the impact of the spotlight and scarcity effects on the bond yield. From a time-series perspective, LSAP operations should lead to a decline in the bond yield, due to massive demand from the BoJ. From a cross-sectional perspective, two channels can be identified from the level of the yield. On the one hand, the broad demand range from the BoJ raises the price of any bond that is either on the target list or which has actually been recently purchased. On the other hand, according to Amihud and Mendelson (1991), the degree of illiquidity should be a discounting factor for the bond price. In the cross-section of the yield level, increasing scarcity should raise the bond yield. It is an empirical question as to which channel has a larger impact.

Hypothesis 5 *Bond yields are lower on BoJ's auction days because of bond spotlight effects, captured by inclusion in the target list or purchase of a particular bond, which raise bond prices.*

Hypothesis 6 *Bond yield, which is lower due to the spotlight effect, is mitigated by greater bond illiquidity (scarcity).*

Like liquidity, we introduce three bond life stages that distinguish between fresh, old, and shadow bonds. Similar arguments are applied to the effect on yield. The spotlight effect reflects increased demand for bonds, but the effect is countered by scarcity. Scarcity contributes to higher prices because of the severe supply–demand imbalance, but this is partially offset by greater illiquidity.

Hypothesis 7 (a) *The spotlight effect on the yield of old bonds is greater than that on the yield of fresh bonds.* (b) *The spotlight effect on the yield of shadow bonds is mitigated by their high illiquidity.*

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 Comprehensive Monetary Easing (CE) program, the BoJ conducted auctions of financial assets up to 5 trillion yen per month, including about 1.5 trillion yen in JGBs. The BoJ gradually increased the program's total purchase amount.

Haruhiko Kuroda's nomination as governor of the BoJ (February 28, 2013) stimulated market speculation about the potential expansion of 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 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 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.[5]

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

[5]According to the BoJ's LSAP program history, we can define three periods, listed as follows:

CE	October 28, 2010 to April 3, 2013	29 months
QQE1	April 4, 2013 to October 30, 2014	19 months
QQE2	October 31, 2014 to January 28, 2016	15 months

CEbase	June 1, 2011 to January 31, 2012	8 months
CE0	February 1, 2012 to February 27, 2013	13 months
QQEX	February 28, 2013 to May 31,2013	3 months
QQE1	June 1, 2013 to October 30, 2014	17 months
QQE2	October 31, 2014 to January 28, 2016	15 months

We designate June 1, 2011, to January 31, 2012 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 CE0, the BoJ gradually increased the purchase amount of JGBs. We then have the QQEX period between the CE0 and QQE1 periods (February 28, 2013, through May 31, 2013), when Kuroda was approved 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 over time.

[Figure 1 about here.]

As shown in Figure 1, a large fluctuation is observed on the QQE announcement day on April 4, 2013. However, we are more concerned with the two months around the announcement of QQE. After 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 may 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.

[Figure 2 about here.]

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.

In Table 1, the panels (a) to (c) display the number of operations, the total purchase amounts, and the average auction sizes for the five periods, respectively.

[Table 1 about here.]

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 result indicates that the BoJ had been trying to proceed with huge amounts of purchases while minimizing the influence of each purchase on the market.

4.2 BoJ's Auctions

We now describe the timeline of the BoJ's auctions. On the day the BoJ executes an operation, it proceeds with an auction through its financial network system (BOJ-NET) according to the following schedule,

Time	Auction
10:10	Announce today's operation
11:40	Bid submission cutoff
Around 12:00	Notification of results
Two days later	Settlement

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

5 Data and Descriptive Statistics

5.1 Liquidity Measures and Yield

Our data consist of daily observations in the universe of nominal coupon JGBs from February 1, 2009, to January 28, 2016.[6] Their original maturities are two, five, 10, 20, 30, and 40 years. The daily price and best quote data at the end of each trading day

[6] Inflation-linked bonds are excluded from our sample.

are provided by Bloomberg.[7] We use the last price, the bid price, and the ask price after June 1, 2011, to investigate the LSAP's effect in the next section and thereafter.[8]

We first define our liquidity measure, the bid–ask spread. It can show one aspect of market liquidity that is meaningful only for small lot orders and indicates how market makers (dealers) perceive liquidity conditions.[9] The percentage of the bid–ask spread of security n at time t is defined as

$$sprd_{n,t} = \frac{ask - bid}{midprice} \times 100, \tag{1}$$

where *midprice* is the average of the ask and bid prices. The change in the bid–ask spread from time t to time $t + \Delta t$ is

$$\Delta sprd_{n,t,\Delta t} = sprd_{n,t+\Delta t} - sprd_{n,t}. \tag{2}$$

We compute the bid–ask spreads of individual securities. Figure 3 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 2 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, owing to 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 with time. Our analysis aims to capture both changes through time and the drivers of the cross-sectional dispersion due to the QE interventions.

[Figure 3 about here.]

[Table 2 about here.]

We next define the bond yield. Let $Y_{n,t}$ be the yield to maturity of government bond n at time t;

$$Y_{n,t} = \frac{coupon_n + \frac{100 - P(n,t)}{\tau_n}}{P(n,t)} \times 100 \quad (\%), \tag{3}$$

[7]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.

[8]We inspect the data before May 31, 2011, which are qualitatively different from the data after June 1, 2011, because Bloomberg started incorporating quotes posted to the Bloomberg Electric Trading Platform around May 2011. Hence we decided to use only the data after June 1, 2011.

[9]The quotes reported by Bloomberg are not firm quotes.

where $coupon_n$ is the coupon rate (%) of security n, $\tau_{n,t}$ is the remaining maturity of security n at time t, and $P_{n,t}$ is the price of security n at time t.[10] The change in yield from time t to time $t + \Delta t$ is

$$\Delta Y_{n,t,\Delta t} = Y_{n,t+\Delta t} - Y_{n,t}. \tag{4}$$

Table 3 presents descriptive statistics of the yields. As shown in Figure 1 and Table 3, the yields of short-, mid- and long-term JGBs declined by 4 bps, 20 bps, and 40 bps, respectively, between CEbase and QQEX and by 8 bps, 20 bps, and 37 bps, respectively, between QQEX and QQE2.

[Table 3 about here.]

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 auction is collected from Reuters News and Nikkei Telecom.[11]

5.2 Spotlight Variables

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

We now construct the spotlight effect variables caused by an auction announcement of the targeted securities. The announcement of a security being targeted for the BoJ's auction may have a different impact between being targeted the first time and being targeted the second or later time and we construct the following variables,

- $ftarget_{n,t}$: First target dummy, which equals one when security n is targeted the first time at time t
- $target_{n,t}$: Target dummy, which equals one when security n is targeted for the auction at time t for the second or later time

[10] We use the daily last price data for $P_{n,t}$ in the empirical analysis.

[11] Other data are obtained as follows. Information about newly issued bonds is from the MOF. We also obtained the interest rate on a constant maturity basis, 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 S&P and the Japan Exchange Group. We obtain information on the Fed's and ECB's program announcements from their respective websites.

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.[12] 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. The pre-analysis, which is not shown in this paper, suggests that the BoJ is likely to purchase a bond that it bought in the previous operation after CE0. To examine this effect on market liquidity and bond yield, we set the following variable,

$purchased_{n,t}$: Amount purchased in the previous auction of targeted security n as a percentage of its amount outstanding

5.3 Scarcity Variables

We intend to investigate the impact the scarcity of a bond (or its substitutes) has on market liquidity or bond yield. The BoJ's LSAPs have a significant impact on the bond supply, as indicated by Figure 4, 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.[13]

[Figure 4 about here.]

As shown in Figure 4, 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

$$h_{n,t} = \frac{H_{n,t}/O_{n,t}}{\sum_n H_{n,t}/\sum_n O_{n,t}}, \tag{5}$$

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

[12] 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.

[13] We did not include the amount issued by the auction for enhanced liquidity.

scarcity on liquidity. We define the BoJ's relative holding ratio of substitutes of security n at time t as

$$sh_{n,t} = \frac{sH_{n,t}/sO_{n,t}}{\sum_n H_{n,t}/\sum_n O_{n,t}}, \tag{6}$$

where $sO_{n,t}$ is defined as all bonds outstanding with remaining maturities between $u-1$ and $u+1$ years if the remaining maturity τ 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 Three Bond Life Stages in Liquidity

We further explore the liquidity term structure by introducing three bond life stages according to the literature on bond liquidity.

First, the liquidity difference between on- and off-the-run bonds is well known by practitioners as well as academics (e.g., Boudoukh and Whitelaw 1993, Fleming 2003). Second, the liquidity difference between short- and long-term bonds is upward sloping (Goyenko et al. 2011). This result reflects increasing duration risk. Third, Amihud and Mendelson (1991) indicate that the time to maturity of two bonds is not the full story of the liquidity difference. Original maturity carries certain ownership characteristics that affect the level of liquidity when the time to maturity of one long-term bond gets shorter-term to maturity (Krishnamurthy 2002).

We therefore specify three distinct bond life stages corresponding to the bond liquidity levels mentioned above. The three life stages are for fresh, old, and shadow bonds. Fresh bonds are those within one year of issuance. These bonds have sufficient availability for dealers to make market. In contrast to fresh bonds, shadow bonds have time to maturity that enters into the range of other original maturity bonds. For example, original 10-year bonds with a time to maturity of 4.5 years have substitutable bonds with an original maturity of five years. Therefore, these bonds are no longer the first choice for someone who wishes to trade four- to five-year-maturity bonds. Old bonds (Krishnamurthy 2002) become illiquid due to the shrinkage of free float as a result of the lock-away effect of long-term investors (Amihud and Mendelson 1991). We define old bonds as those between fresh and shadow bonds. These three groups capture unique features of the bond liquidity term structure.

To capture these effects, we introduce dummy variables which corresponds to three distinct life stage groups, fresh, old, and shadow bonds. We define $fresh_{n,t}$ as a dummy variable that equals one when the bond was issued within one year. We introduce the dummy $Shadow_{n,t}$, which equals one after the remaining time of a five-, 10-, 20-, 30-, or 40-year bond reaches less than two, five, 10, 20, or 30 years, respectively. We further define $old_{n,t}$ as a dummy variable that equals one when the bond has been issued since over one year but before it reaches the shadow range of its life stage.

[Figure 5 about here.]

Figure 5 shows the BoJ's purchased amounts split among fresh, old, and shadow bonds. In the CEbase period, the BoJ purchases almost the same amounts of fresh, old, and shadow bonds, but it increasingly purchases fresh bonds after the QQEX period and the ratio of fresh bonds is about 70% in QQE2.

5.5 Other Variables

We use the daily changes in bid–ask spread and yield for time-series analysis. We need to control days the BoJ announced the LSAP program. The announcement may have an immediate impact on the JGB market. In order to examine its impact, we define

$program_t$: Dummy variable on the day of the LSAP program announcement[14]

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 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; $cglbond_t$, the average of the daily change in the yield of 10-year German government *Bundeswertpapiere* and that of 10-year US Treasury bonds; and $ccs_{n,t}$, the change in the US dollar/Japanese yen (USD/JPY) floating-for-floating cross-currency swap for security n.[15] We further define the change in the JGB VIX, $cvix$. This index measures the model-free 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

[14]The announcement dates in our sample period are eight days: August 4, 2011, October 27, 2011, February 14, 2012, September 19, 2012, October 30, 2012, December 20, 2012, April 4, 2013, and October 31, 2014.

[15]Using 12-month, 18-month, 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.

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.[16] We adjust all the variables observed in Europe or the United States in consideration of time zone differences.

BoJ's auctions and new issue auctions are not scheduled the same day. The market is aware that large amounts of new issues occur periodically and it therefore behaves 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: $preis_{n,t}$, the logarithm of the offer amount of security n issued the day before its maturity is within two years of the newly issued bond's maturity; $issue_{n,t}$, the logarithm of the offer amount of security n issued the day its maturity is within two years of the newly issued bond's maturity; and $aftis_{n,t}$, the logarithm of the offer amount of security n issued the day after its maturity is within two years of the newly issued bond's maturity.

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 through the practice of 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 yield and liquidity. To identify underpriced securities, we use Svensson's (1995) model. Svensson's fitting error $svnerr_{n,t}$ of security n at time t is defined as[17]

$svnerr_{n,t}$: The difference between the observed yield of each security and the corresponding estimate from Svensson's model

When the BoJ conducts an auction, it announces not only target bonds but also drop bonds. The BoJ drops the bonds cheapest to deliver for futures contract throughout the periods, and before introducing QQE, in addition to them, it drops bonds of its holding ratio were very high. To control these impact on spread and yield, we define

$fdrop_{n,t}$: First drop dummy, which equals one when security n is dropped from the target list the first time at time t

$drop_{n,t}$: Drop dummy, which equals one when security n is dropped from the target list for the second or later time.

[16]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).

[17]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 $svnerr_{n,t}$ as the difference between the observed yield of each security and the corresponding estimate of Svensson's model.

We also use the characteristics of bonds, such as the bond coupon, $coupon_n$, and the logarithm of the outstanding amount of security n, $lnO_{n,t}$.

6 Empirical Analysis of Liquidity

In this section, we conduct three empirical analyses of the impact of QE on the JGB market using the bid–ask spread as a proxy for liquidity. We investigate the following four hypotheses.

Hypothesis 1 *Since the spotlight effect at the macro level is stronger than the scarcity effect, QE, on average, induces an improvement in liquidity.*

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

Hypothesis 3 *The scarcity of bonds increases illiquidity, which is accentuated when there is a scarcity of even substitutable bonds, such as those with similar maturity.*

Hypothesis 4 (a) *The spotlight effect on the liquidity of old bonds is greater than that on the liquidity of fresh bonds.* (b) *The spotlight effect on the liquidity of shadow bonds is mitigated by their high illiquidity.*

We first test for overall liquidity improvement by comparing average liquidity levels between periods. In Section 6.2 and 6.3, we investigate the hypotheses by time-series and cross-sectional regressions. In Section 6.4, we further explore impact on market liquidity introducing three life stages.

6.1 Overall Impact of the QQE Periods on Liquidity

The descriptive statistics in Table 2 and differences in the term structure of each period in Figure 3 indicate the bid–ask spread got narrower before introducing the QQE by governor Kuroda, and then, it got slightly wider in QQE1 and QQE2. We confirm the change in bid–ask spread statistically by comparing the average spread period by period.

[Table 4 about here.]

Table 4 shows the results of a Welch two-sample t-test. Comparisons with the CEbase period confirm the improvement in liquidity for all bonds except the three- to 10-year bucket in the CE0 period. The bid–ask spreads in QQEX are also significantly narrower than those in CE0 for all remaining maturities. On the other hand, the results of comparisons with the QQE1 to QQEX and those with QQE2 to QQE1 show the deterioration in market liquidity except the longer than 10-year bonds in the QQE1 and the three- to 10-year bonds in the QQE2. From these comparisons with the preceding period, the improvements in liquidity are observed in former two periods and deteriorations are observed in latter two periods. The results are consistent with Hypothesis 1.

There is a largest reduction of the spread for bonds with a maturity longer than 10 years throughout four periods. Their average spread in QQE1 is significantly narrower than in QQEX, though the results for other maturity buckets change their signs. These results are consistent with the BoJ shifting toward longer-maturity bonds in the QQE periods. The reduction in spread for bonds with a maturity longer than 10 years in CE0 is significantly estimated to be -7.184, but in CE0, the BoJ didn't purchase longer-term bonds aggressively as described in Table 1(b).

In this comparison, we do not adjust market factors; other factors, such as the European financial crisis, may have a diminishing influence on the liquidity of long-term bonds. In the following subsection, we perform time-series and cross-sectional regressions controlling these effects.

6.2 Daily changes in the Bid–Ask Spread

Spotlight effects occur when the LSAP programs are implemented. Information on the purchasing program, such as the target list and purchase amounts, is disclosed the morning of the BoJ's auction day, as explained in detail in Section 4.2. These specific announcements create a spotlight effect on marketwide changes in liquidity. Thus our time-series specification is determined by conducting a panel regression with bond fixed effects. The effects on individual bonds are examined by cross-sectional regression with time fixed effects in the following subsection.

We examine spotlight effects on time-series liquidity innovation through daily changes in 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 focus on such a bond. We investigate whether inclusion in an auction target list or actual purchase tightens the bid–ask spread. We consider the following panel regression model of change in spreads with bond fixed effects,

$$\begin{aligned} \Delta sprd_{n,t,t-1} &= \alpha + \sum_i \beta_i Spotlight^i_{n,t} + \sum_j \gamma_j Lagged^j_{n,t-1} + \sum_k \theta_k Macro^k_t \\ &\quad + \sum_l \kappa_l Newly^l_{n,t} + \sum_m \lambda_m Control^m_{n,t} + \epsilon_{n,t}, \qquad (7) \end{aligned}$$

where $\Delta sprd_{n,t,t-1}$ is the change in the bid–ask spread of security n from $t-1$ to t and $\{Spotlight^i_{n,t}\}$ includes variables for examining the spotlight effect, such as the first target dummy, $ftarget_{n,t}$; the dummy for being targeted the second or later time, $target_{n,t}$; and the amount purchased in the previous auction, $purchased_{n,t}$. We add two lagged variables, $\{Lagged^j_{n,t-1}\}$, such as the change in the bid–ask spread, $\Delta sprd_{n,t-1,t-2}$, and the change in yield, $\Delta Y_{n,t-1,t-2}$. The term $\{Newly^l_{n,t}\}$ includes $preis_{n,t}$, $issue_{n,t}$, and $aftis_{n,t}$, which equal the logarithm of the offered amount if the substitute bond is newly issued the previous day, the same day, or the following day, respectively. The variable $\{Macro^k_t\}$ includes domestic and global indicators, such as $ctopix_t$, $cglbond_t$, $cvix_t$, $feda^-_t$, $feda^+_t$, $ecba^-_t$, and $ecba^+_t$, and $\{Control^m_{n,t}\}$ includes a program announcement date dummy, $program_t$; the first drop dummy, $fdrop$; the dummy for being dropped the second or later time, $drop_{n,t}$; and the remaining time to maturity, τ; and its square, which characterizes the term structure. The variable $\epsilon_{n,t}$ represents the error term.

[Table 5 about here.]

We run the regression of this model with individual security dummies (bond fixed effect). Table 5 presents the regression results of change in the bid–ask spread. We calculate the significance of the coefficients from two-way cluster-robust standard errors (Cameron et al. 2011). Three variables are related to the spotlight effect, $ftarget_{n,t}$, $target_{n,t}$ and $purchased_{n,t}$. Among the three, $ftarget$ has a marginally significant coefficient -0.9702 (t-value $= -1.75$) for CEbase and $purchased$ also has a marginally significant -0.0398 (t-value $= -1.75$) for QQE2. Though the coefficients for being a target the first time and a target the second time or later are estimated with a negative sign in CEbase and CE0, they are not statistically significant at the 5% level. In QQE1 and QQE2, the coefficients for first target dummy and the amount purchased in the previous auction are estimated with a negative sign, but they are also insignificant at the 5% level. These means the spotlight effects are not observed for the daily change in the bid–ask spread and we cannot confirm the hypotheses from this analysis. Since most of the bonds belong to the targeted list, there is no more special effect.

The program announcement for QQE2 shows the largest improvement in liquidity, which is a 2.767 bps reduction of the bid–ask spread (t-value $= -8.46$). However, the impact of the QQEX announcement[18] is significantly positive, at 1.082, which indicates the deterioration of liquidity due to surprising and unknown policy changes for the market participants. A positive coefficient 1.9551 for $ftarget$ in QQEX may also be caused by their surprise to the BoJ's expansion of targeted bonds.

Among macroeconomic variables, significant negative effects are associated with the Fed and ECB program announcement date ($-$) dummies in QQE2. This means that the spread is tightened when the yield of the US Treasury or German government bond declines in response to the Fed's or ECB's program announcement.

[18]The announcement of the BoJ's introduction of QQE.

6.3 Cross-Sectional Differences in Bid–Ask Spreads

In this subsection, we investigate how spotlight and scarcity effects affect the level of liquidity across the JGBs. We ask whether spotlight effects such as target list inclusion or actual purchase have a positive impact on liquidity and whether the level of liquidity affects the state of scarcity of the bonds. Thus we perform a cross-sectional analysis of the bid–ask spread in terms of levels instead of 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,

$$sprd_{n,t} \quad = \quad \alpha + \sum_i \beta_i Spotlight^i_{n,t} + \sum_j \gamma_j Scarcity^j_{n,t} + \sum_k \theta_l Control^k_{n,t} + \epsilon_{n,t}, \quad (8)$$

where $\{Spotlight^i_{n,t}\}$ includes variables for examining the spotlight effect, such as the first target dummy, $ftarget_{n,t}$; a dummy for being targeted the second or later time, $target_{n,t}$; and the amount purchased in the previous auction, $purchased_{n,t}$. The program announcement date dummy is excluded for regressing the time fixed effects model. The term $\{Scarcity^j_{n,t}\}$ includes the BoJ's relative holding ratio, $h_{n,t}$, and the BoJ's relative holding ratio of substitutes, $sh_{n,t}$. The term $\{Control^k_{n,t}\}$ includes the first drop dummy, $fdrop$; a dummy for being dropped the second or later time, $drop_{n,t}$; a coupon; the logarithm of the amount outstanding, $lnO_{n,t}$; and the remaining time to maturity, τ; and its square, which characterize the term structure of the bid–ask spread. The variable $\epsilon_{n,t}$ represents the error term. We run the regression of this model with daily time dummies.

[Table 6 about here.]

Table 6 presents the results for the cross-sectional regression of the bid–ask spread for the five periods. The dependent variable is the end-of-day spread in basis points and the regression equation is presented in Eq. (8). The adjusted R-squared values of the cross-sectional regression of the bid–ask spread are very high, from 0.654 to 0.907.

Among the variables related to the spotlight effect, that for a bond purchased in a previous operation has significantly negative coefficients in CE0 (-0.183), QQE1 (-0.087), and QQE2 (-0.035). This result is consistent with Hypothesis 2 (spotlight effect improves the liquidity of a bond). The significant negative coefficient for first target dummy in CEbase also supports Hypothesis 2. The target dummy has a significantly positive coefficient in CE0 (0.726) and QQE1 (0.902), however. As mentioned, in QQE1 and QQE2, the BoJ specified targets for nearly all the bonds in the bucket, so that the target list does not carry a signal of the spotlight effects.

Two variables related to the scarcity effect are the relative holding ratio of a bond ($h_{n,t}$) and that of its substitutes ($sh_{n,t}$). The relative holding ratio of a bond exhibits significant explanatory power throughout the periods. The relative holding ratio of its substitutes affects the illiquidity of a bond in CEbase, QQE1 and QQE2. The higher the holding ratio, the larger the bid–ask spread, as expected, which is consistent with Hypothesis 3. The relative scarcity explains the cross-sectional differences of bid–ask spread, while the marketwide scarcity worsening the liquidity in the entire JGB market. Among control variables, the amount outstanding has significant coefficient throughout the periods. Larger outstanding keep the bid–ask spread from widening.

6.4 Liquidity in the Three Bond Life Stages

In this subsection, we investigate various relations between liquidity and spotlight and scarcity effects in the three bond life stages, for fresh, old, and shadow bonds. We first add old and shadow bond dummies to the cross-sectional regression model in Eq. (6) to examine the overall effect of life stages on the bid–ask spread,

$$\begin{aligned} sprd_{n,t} &= \alpha + \sum_i \beta_i Spotlight^i_{n,t} + \sum_j \gamma_j Scarcity^j_{n,t} + \sum_l \kappa_l Stage^l_{n,t} \\ &\quad + \sum_k \theta_k Control^k_{n,t} + \epsilon_{n,t}, \end{aligned} \tag{9}$$

where $\{Spotlight^i_{n,t}\}$ includes $ftarget_{n,t}$, $target_{n,t}$, and $purchased_{n,t}$ and $\{Scarcity^j_{n,t}\}$ includes $h_{n,t}$ and $sh_{n,t}$, the same variables as in the cross-sectional regression. The term $\{Stage^l_{n,t}\}$ includes a dummy indicating whether the bond has been issued since over one year but is not in the shadow area, $old_{n,t}$; and a dummy indicating whether the bond has reached the shadow area of time remaining, $shadow_{n,t}$. These two variables show whether or not the impact is different for each term structure stage. The term $\{Control^k_{n,t}\}$ includes $fdrop_{n,t}$, $drop_{n,t}$, $coupon$, $lnO_{n,t}$, and τ and its square and $\epsilon_{n,t}$ represents the error term. We run the regression of this model with daily time dummies.

[Table 7 about here.]

Table 7 presents the results of the cross-sectional regression for the bid–ask spread with the bond life stage dummies. The life stage dummies show that the bid–ask spreads of fresh bonds are tighter than those of old bonds until QQEX, but in QQE1 and QQE2, this measure becomes indifferent. This indifference of the liquidity must result from the spotlight effect on old bonds. On the other hand, the bid–ask spreads of shadow bonds are always wider than those of the fresh bonds. The differences of the spread are between 0.238 bps and 3.38 bps. These results are consistent with Hypothesis 4(a).

We now investigate whether these life stage results come from the spotlight or scarcity effect. We add the cross terms of the old and shadow bond dummies with the spotlight and scarcity effects variables to examine the structural breaks along bond life stages,

$$\begin{aligned} sprd_{n,t} &= \alpha + \sum_i \beta_i Spotlight^i_{n,t} + \sum_j \gamma_j Scarcity^j_{n,t} \\ &+ \sum_i \sum_l \kappa_{i,l} Stage^l_{n,t} \times Spotlight^i_{n,t} + \sum_j \sum_m \lambda_{j,m} Stage^m_{n,t} \times Scarcity^j_{n,t} \\ &+ \sum_k \theta_k Control^k_{n,t} + \epsilon_{n,t}, \end{aligned} \tag{10}$$

where the term $\{Stage^l_{n,t} \times Spotlight^i_{n,t}\}$ includes a dummy indicating whether the bond has been issued since over one year but is not in the shadow area, $old_{n,t}$; a dummy indicating whether the bond reached the shadow area, $shadow_{n,t}$; and the cross term of the two life stage dummy variables with the three spotlight variables, with the term $\{Stage^m_{n,t} \times Scarcity^j_{n,t}\}$ including the old bond dummy, the shadow bond dummy, and their cross terms with the two scarcity effect variables. The terms $\{Spotlight^i_{n,t}\}$, $\{Scarcity^j_{n,t}\}$, and $\{Control^k_{n,t}\}$ include the same variables as Eq. (9) and $\epsilon_{n,t}$ represents the error term. We run Eq. (10) with daily time dummies.

[Table 8 about here.]

Table 8 presents the results of the cross-sectional regression for the bid–ask spread with the bond life stage dummies and their cross terms with the spotlight and scarcity effect variables. The relative holding ratio of the bond is estimated as a positive value for the old and shadow bonds throughout the periods. (See the lines of "Relative holding ratio of the bond" and its cross term with old or shadow bonds in Table 8.) The BoJ's higher holding ratio is associated with the deterioration of liquidity in general. On the other hand, fresh bonds show better liquidity associated with the relative holding ratio. A rising holding ratio works as a signal of the strong demand from the BoJ. The Hypothesis 4(b) is not supported for the fresh bonds.

Old and shadow bonds experience better liquidity when a bond is purchased in the previous operation for all periods except QQE1 and CEbase, respectively. Since the BoJ's purchase focuses more on the fresh bonds, an old or a shadow bond attracts more attention when it was bought in the previous operation. These results support Hypothesis 4(a).

7 Empirical Analysis of the LSAP Effect on Yield

In this section, we investigate the following hypotheses.

Hypothesis 5 *Bond yields are lower on BoJ's auction days because of bond spotlight effects, captured by inclusion in the target list or purchase of a particular bond, which raise bond prices.*

Hypothesis 6 *Bond yield, which is lower due to the spotlight effect, is mitigated by greater bond illiquidity (scarcity).*

Hypothesis 7 (a) *The spotlight effect on the yield of old bonds is greater than that on the yield of fresh bonds.* (b) *The spotlight effect on the yield of shadow bonds is mitigated by their high illiquidity.*

7.1 Daily Changes in Yield

We examine the spotlight and scarcity effects on bond yield through daily changes in yield. The spotlight effect is expected to affect the bond price significantly because it indicates strong demand for government bonds. Nomination to the target list and actual purchase contribute to the daily price change. Since daily changes in scarcity are very small and the disclosures of BoJ holdings are monthly or every 10 days, we exclude the scarcity effect variables from the time-series regression,

$$\begin{aligned}\Delta Y_{n,t,t-1} &= \alpha + \sum_i \beta_i Spotlight^i_{n,t} + \sum_j \gamma_j Lagged^j_{n,t-1} + \sum_k \theta_k Macro^k_{n,t} \\ &+ \sum_l \kappa_l Newly^l_{n,t} + \sum_m \lambda_m Control^m_{n,t} + \epsilon_{n,t}, \qquad (11)\end{aligned}$$

where $\Delta Y_{n,t,t-1}$ is the change in the yield of security n from $t-1$ to t and $\{Spotlight^i_{n,t}\}$ includes variables for examining the spotlight effect, such as the first target dummy, $ftarget$; the dummy for being targeted the second or later time $target_{n,t}$; and the amount purchased in the previous auction, $purchased_{n,t}$. We add two lagged variables, $\{Lagged^j_{n,t-1}\}$, such as the change in yield, $\Delta Y_{n,t-1,t-2}$, and Svensson's yield curve fitting error, $svner_{n,t-1}$, which are not used in the estimation for the bid–ask spread. The term $\{Newly^l_{n,t}\}$ includes $preis_{n,t}$, $issue_{n,t}$, and $aftis_{n,t}$, which equal 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 $\{Macro^k_{n,t}\}$ includes domestic and global indicators, such as $ctopix_t$, $cglbond_t$, $ccs_{n,t}$, $feda^-_t$, $feda^+_t$, $ecba^-_t$, and $ecba^+_t$, and $\{Control^m_{n,t}\}$ includes a program announcement date dummy, $program_t$; the first drop dummy, $fdrop$; dummy for being dropped the second or later time, $drop_{n,t}$; the remaining time to maturity, τ; and its square, which characterize the term structure. We use the change in the USD/JPY cross-currency swap to control for the change in demand by foreign investors instead of the change in JGB VIX, which is an important parameter for market making risk. The variable $\epsilon_{n,t}$ represents the error term.

[Table 9 about here.]

We run the regression of this model with individual security dummies (bond fixed effect). Table 9 shows the results of time-series regression on yield change. We calculate the significance of the coefficients from two-way cluster-robust standard errors.

The spotlight effect captured by inclusion in the target list increases the yield decline throughout the periods and significant negative coefficients are estimated in CEbase, QQE1, and QQE2. In CEbase period, the bond price is significantly higher after a single inclusion in the target list. These results are consistent with Hypothesis 5. Although the amount purchased $purchased_{n,t}$ has positive coefficient, they are all insignificant at 5 % level.

Svensson yield curve fitting error have significant negative coefficients throughout five periods. This results indicates that the expensive bonds today are adjusted to be lower price tomorrow. The program announcements in QQEX and QQE2 contribute to the bond price decline as well. The coefficient for QQEX shows the largest decline in yield (8.31 bps) in a day, which indicates the impact of the announcement of the QQE. The announcement in QQE2 has smaller impact on yield than that in QQEX.

7.2 Cross-Sectional Differences in Yields

In this subsection, we investigate how spotlight and scarcity effects affect the level of yield across the JGBs. We ask whether spotlight effects such as an inclusion of the target list or actual purchase have a negative impact on yield. Thus we perform a cross-sectional analysis of the yield in terms of levels instead of changes. We examine whether the variables measuring the spotlight or scarcity effect can explain the cross-sectional differences in bond yields. The following regressions are performed,

$$Y_{n,t} = \alpha + \sum_i \beta_i Spotlight^i_{n,t} + \sum_j \gamma_j Scarcity^j_{n,t} + \sum_k \theta_k Control^k_{n,t} + \epsilon_{n,t}, \quad (12)$$

where $\{Spotlight^i_{n,t}\}$ includes variables for examining the spotlight effect, such as the first target dummy, $ftarget$; dummy for being targeted the second or later time $target_{n,t}$; and the amount purchased in the previous auction, $purchased$. The term $\{Scarcity^j_{n,t}\}$ includes the BoJ's relative holding ratio, $h_{n,t}$, and the BoJ's relative holding ratio of substitutes, $sh_{n,t}$. The term $\{Control^k_{n,t}\}$ includes the first drop dummy, $fdrop$; dummy for being dropped the second or later time $drop_{n,t}$, a coupon; the logarithm of the amount outstanding, $lnO_{n,t}$; the remaining time to maturity, τ, and its square. The variable $\epsilon_{n,t}$ represents the error term. We run the regression of this model with daily time dummies.

[Table 10 about here.]

Table 10 presents the regression results of the cross-sectional model with time fixed effects for the bond yields. The dependent variable is the end-of-day yield in basis points and the regression equation is presented in Eq. (12).

The adjusted R-squared values of the cross-sectional yield are very high, from 0.962 to 0.986. Among the variables related to the spotlight effect, the target dummy has significantly negative coefficients throughout the periods. This finding is consistent with Hypothesis 6. A bond purchased in a previous operation has significantly positive coefficients in CEbase and QQE2. The two variables related to the scarcity effect have opposite effects on yield; the relative holding ratio of a bond and that of its substitutes affect the yield in a negative direction in QQE1 and QQE2. The higher the holding ratio, the lower the bond yield, which indicates the illiquidity increases the market impact. The relative holding ratio of a bond is estimated as also a negative value before QQEX, but those of the substitutes is estimated as a positive value. These results indicates that the market scarcity doesn't mitigate the spotlight effect on yield, it rather accelerates the yield decline, which is incompatible with Hypothesis 6. The bond scarcity amplifies the market impact. Two dummies for being dropped from the target list have significant negative coefficients, which indicates the prices of these bonds rise due to other than the spotlight effect, such as the bond cheapest to deliver for futures contracts.

7.3 Yield in the Three Bond Life Stages

We now investigate the impact of the three life stages on the bond yield instead of the bid–ask spread. We regress the same regressors of Eqs. (9) and (10) for the bond yield model.

[Table 11 about here.]

[Table 12 about here.]

Table 11 presents the results of the cross-sectional regression for the bond yield with the bond life stage dummies. The life stage dummies show the yields of the old bonds are lower than those of fresh bonds for all periods except QQEX. The yield of the old bonds is lower in general, but that of the shadow bonds shows mixed results. The results do not show the illiquidity premium for shadow bonds.

To examine the reasons behind the mixed results, we add the cross terms of the old and shadow bond dummies with the spotlight and scarcity effect variables. Table 12 presents the results of the cross-sectional regression for the yield with the bond life stage dummies and their cross terms with the spotlight and scarcity effect variables. Shadow bond dummies have significantly negative coefficients by adding cross terms. Old and shadow bonds experience lower yields, which means their bond prices rise more than the fresh bond prices do. Furthermore, the estimates of shadow bond dummies are smaller than those of old bond dummies, which indicates that the older the ages, the lower the yield as a whole. The cross terms with the old or shadow and target have negative coefficients throughout the periods. Spotlight effect such as being targeted contributes to lowering the yield not only for fresh bonds but also old or shadow bonds, and furthermore, a greater impact is estimated for old and shadow bonds. This means the BoJ demand boost prices, which supports Hypothesis 7(a).

The relative holding ratio of a bond has a different impact among three bond life stages. Fresh bonds show the higher yield associated with the own holding ratio except QQE1. They are consistent with Hypotheses 6 which is theoretical prediction from Amihud and Mendelson (1986) that higher illiquidity should be compensated by a higher liquidity premium. However, substitutes holding ratio turns to negative in QQE1 and QQE2. These changes can be interpreted as when substitutes holding ratio is higher than market-wide average holding ratio, the yield change of this bond may be amplified due to lack of substitution.

For old and shadow bonds except old bonds after QQE1, the impacts of holding ratio decrease bond yield on the contrary. Scarce availability of bonds causes larger market impact for the BoJ purchase. The spotlight effect is the dominant pricing factor for otherwise illiquid bonds.

8 Concluding Remarks

The LSAPs of the major central banks around the world created scarcity in the assets they targeted while generating a spotlight effect for individual securities. Due to these massive purchase programs during a period of about three years (April 2013 to January 2016), the BoJ's average holding ratio of JGBs jumped from 10% to 37% of the total outstanding amount of these bonds in our sample, perhaps the largest holding ratio any central bank has ever reached. This scarcity can be, therefore, viewed as a supply shock, which has been addressed by many financial economists, market analysts, and central banks in their studies of bond yields. In contrast, we investigate how such a supply shock created by the LSAPs affected both yields and liquidity in the JGB market and how the spotlight effect focuses attention on bonds that were hitherto not actively traded, thus creating rare trading opportunities for eligible bonds in the QE program. This paper explicitly investigates both effects on liquidity and bond yields.

In its purchase operations, the BoJ first announces the overall contents of each LSAP, but the implementation details, such as the schedule of operations and the list of target bonds, are not disclosed in advance. Our results suggest that, in the absence of such concrete information, dealers and investors pay attention to which bonds and how much of each bond the BoJ bought in the previous operation. We also document that the other important effect we investigate, the scarcity effect, gradually penetrates the illiquidity of bonds. The greater the scarcity, the more difficult the market making for the particular bonds becomes, ultimately manifesting itself in worsening illiquidity. This timing difference of spotlight and scarcity effects are observed at macro level in the period-by-period comparative analysis of average bid–ask spread conducted by a Welch two-sample t-test.

In our analysis of these auctions, we confirm a spotlight effect on the bid–ask spread that is associated with the record of purchases but not with inclusion in the target list. Through cross-sectional analysis, we find that the greater the scarcity, the larger the bid–ask spread. Scarcity measured by the bond itself, as well as its substitutable bonds, shows a strong relation with illiquidity. In addition to liquidity effects, we investigate at the micro level the impact of the spotlight and scarcity effects on the bond yield. From a time-series perspective, we find that a LSAP operation leads the decline in the bond yield due to huge demand from the BoJ. From a cross-sectional perspective, among the two channels identified for the level of the yield, the increase in scarcity causes the liquidity to deteriorate and the prices to decline, but this effect is swamped by the spotlight effect. In terms of the three life stages—fresh, old, and shadow—the liquidity of fresh bonds improves when a bond is purchased in the previous operation while the holding ratio of the BoJ is rapidly increasing. It is important to note that illiquidity caused by scarcity amplifies the yield decline rather than adds to the illiquidity premium.

Our results suggest that an aggressive QE program can eventually worsen the market liquidity and increased market impacts in the sovereign bond market while it improves liquidity at the inception. In principle, higher liquidity could mitigate the price impact, but this was not the case for the LSAPs of the BoJ, increased illiquidity ought to be penalized by higher yields, but we find evidence to the contrary. Both these phenomena reflect the strong demand from the purchasing program conducted by the Japanese central bank. Market participants understand and anticipate the stance that the BoJ continues buying until it reaches the planned total amount. Thus bond prices remain higher until the LSAPs end. These results suggest, therefore, that an aggressive QE program such as the LSAPs can eventually adversely affect the government bond market's liquidity and yield, producing a significant negative side effect in the market.

References

Amihud, Y. and Mendelson, H. (1986). "Asset Pricing and the Bid–Ask Spread," *Journal of Financial Economics*, 17(2), 223–249.

Amihud, Y. and Mendelson, H. (1991). “Liquidity, Maturity, and the Yields on U.S. Treasury Securities,” *Journal of Finance*, 46(4), 1411–1425.

Beneish, M. D. and Gardner, J. C. (1995). “Information Costs and Liquidity Effects from Changes in the Dow Jones Industrial Average List,” *Journal of Financial and Quantitative Analysis*, 30(1), 135–157.

Beneish, M. D. and Whaley, R. E. (1996). “An Anatomy of the ‘S&P Game’: The Effects of Changing the Rules,” *Journal of Finance*, 51(5), 1909–1930.

Blattner, T. S. and Joyce, M. A. S. (2016). “Net Debt Supply Shocks in the Euro Area and the Implications for QE,” European Central Bank Working Paper Series 1957.

Boudoukh, J. and Whitelaw, R. F. (1993). “Liquidity as a Choice Variable: A Lesson from the Japanese Government Bond Market,” *Review of Financial Studies*, 6(2), 265–292.

Cahill, M., D’Amico, S., Li, C. and Sears, J. S. (2013). “Duration Risk versus Local Supply Channel in Treasury Yields: Evidence from the Federal Reserve’s Asset Purchase Announcements,” Finance and Economics Discussion Series 2013-35.

Cameron, A. C., Gelbach, J. B. and Miller, D. L. (2011). “Robust Inference with Multiway Clustering,” *Journal of Business and Economic Statistics*, 29(2), 238–249.

Copeland, T. E. and Galai, G. (1983). “Information Effects on the Bid–Ask Spread,” *Journal of Finance*, 38(5), 1457–1469.

D’Amico, S., English, W., Lopez-Salido, D. and Nelson, E. (2012). “The Federal Reserve’s Large-Scale Asset Purchase Programs: Rationale and Effects,” *Economic Journal*, 122, 415–446.

D’Amico, S., Fan, R. and Kitsul, Y. (2013). “The Scarcity Value of Treasury Collateral: Repo Market Effects of Security-Specific Supply and Demand Factors,” Federal Reserve Bank of Chicago Working Papers 2013-22.

D’Amico, S. and King, T. B. (2013). “Flow and Stock Effects of Large-Scale Treasury Purchases: Evidence on the Importance of Local Supply,” *Journal of Financial Economics*, 108(2), 425–448.

Fleming, M. J. (2003). “Measuring Treasury Market Liquidity,” *Economic Policy Review*, 9(3), 83–108.

Friewald, N., Jankowitsch, R. and Subrahmanyam, M. G. (2012). “Illiquidity or Credit Deterioration: A Study of Liquidity in the US Corporate Bond Market during Financial Crises,” *Journal of Financial Economics*, 105(1), 18–36.

Fukunaga, I., Kato N. and Koeda, J. (2015). "Maturity Structure and Supply Factors in Japanese Government Bond Markets," *Monetary and Economic Studies*, 33, Institute for Monetary and Economic Studies, Bank of Japan, 45–95

Goyenko, R., Subrahmanyam, A. and Ukhov, A. (2011). "The Term Structure of Bond Market Liquidity and Its Implications for Expected Bond Returns," *Journal of Financial and Quantitative Analysis*, 46(1), 111–139.

Greenwood, R. and Vayanos, D. (2010). "Price Pressure in the Government Bond Market," *American Economic Review: Papers & Proceedings*, 100, 585–590.

Greenwood, R. and Vayanos, D. (2014). "Bond Supply and Excess Bond Returns," *Review of Financial Studies*, 27(3), 663–713.

Harris, L. and Gurel, E. (1986). "Price and Volume Effects Associated with Changes in the S&P 500 List: New Evidence for the Existence of Price Pressures," *Journal of Finance*, 41(4), 815–829.

Iwatsubo, K. and Taishi, T. (2017). "Quantitative Easing and Liquidity in the Japanese Government Bond Market," *International Review of Finance*, forcoming, irfi.12134.

Joyce, A. S. M. and Tong, M. (2012). "QE and the Gilt Market: A Disaggregated Analysis," *Economic Journal*, 122, 348–384.

Krishnamurthy, A. (2002). "The Bond/Old-Bond Spread," *Journal of Financial Economics*, 66, 463–506.

Lam, W. R. (2011). "Bank of Japan's Monetary Easing Measures: Are They Powerful and Comprehensive?" International Monetary Fund Working Paper 11-264.

McInish, T. H. and Wood, R. A. (1992). "An Analysis of Intraday Patterns in Bid/Ask Spreads for NYSE Stocks," *Journal of Finance*, 47(2), 753–764

Modigliani, F. and Sutch, R. (1966). "Innovations in Interest Rate Policy," *American Economic Review*, 56, 178–197.

Rogers, J. H., Scotti, C. and Wright, J. H. (2014). "Evaluating Asset-Market Effects of Unconventional Monetary Policy: A Cross-Country Comparison," International Finance Discussion Papers 1011.

Schlepper, K., Hofer, H., Riordan R. and Schrimpf, A. (2017). "Scarcity Effects of QE: A Transaction-level Analysis in the Bund Market," BIS Working Papers 625.

Schuster, P. and Uhrig-Homburg, M. (2012). "The Term Structure of Bond Market Liquidity Conditional on the Economic Environment: An Analysis of Government Guaranteed Bonds," Working Paper.

Song, Z. and Zhu, H. (2016). "QE Auctions of Treasury Bonds," Working Paper, SSRN, http://ssrn.com/abstract=2756674.

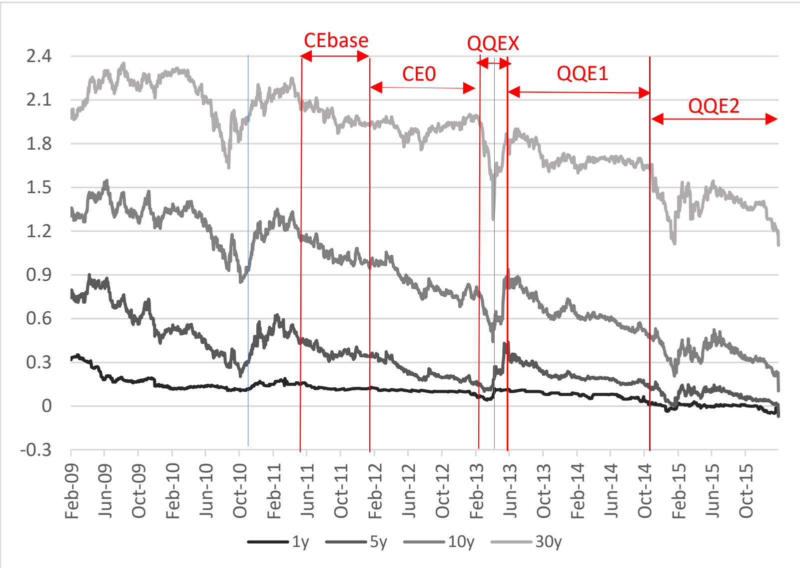
Stoll, H. (1978). "The Supply of Dealer Services in Securities Markets," *Journal of Finance*, 33(4), 1133–1151.

Svensson, L. E. O. (1995). "Estimating Forward Interest Rates with the Extended Nelson & Siegel Method," *Sveriges Riksbank Quarterly Review*, 3, 13–26.

Ueda, K. (2013). "The Response of Asset Prices to Monetary Policy under Abenomics," Center for International Research for Japanese Economy Discussion Papers F-894.

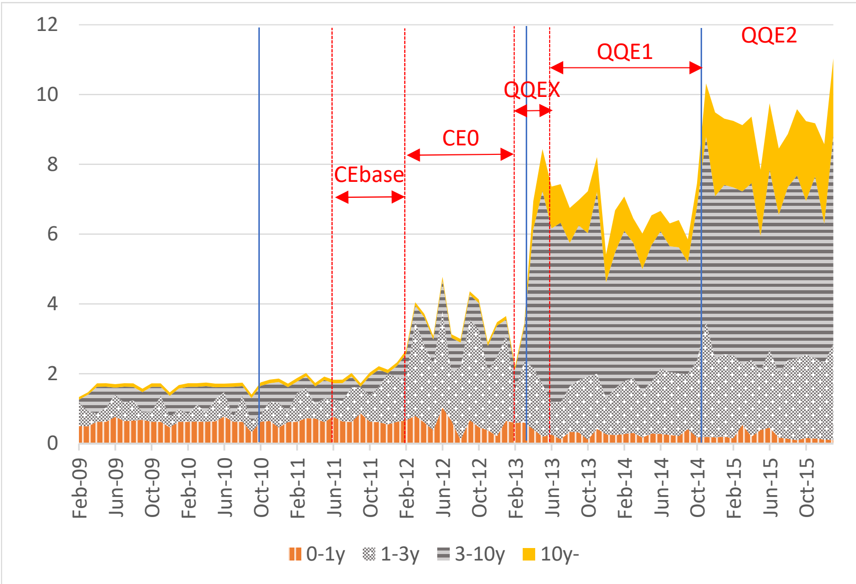
Vayanos, D. and Vila, J. L. (2009). "A Preferred-Habitat Model of the Term Structure of Interest Rates," NBER Working Paper 15487.

Figure 1: Historical yield of JGBs



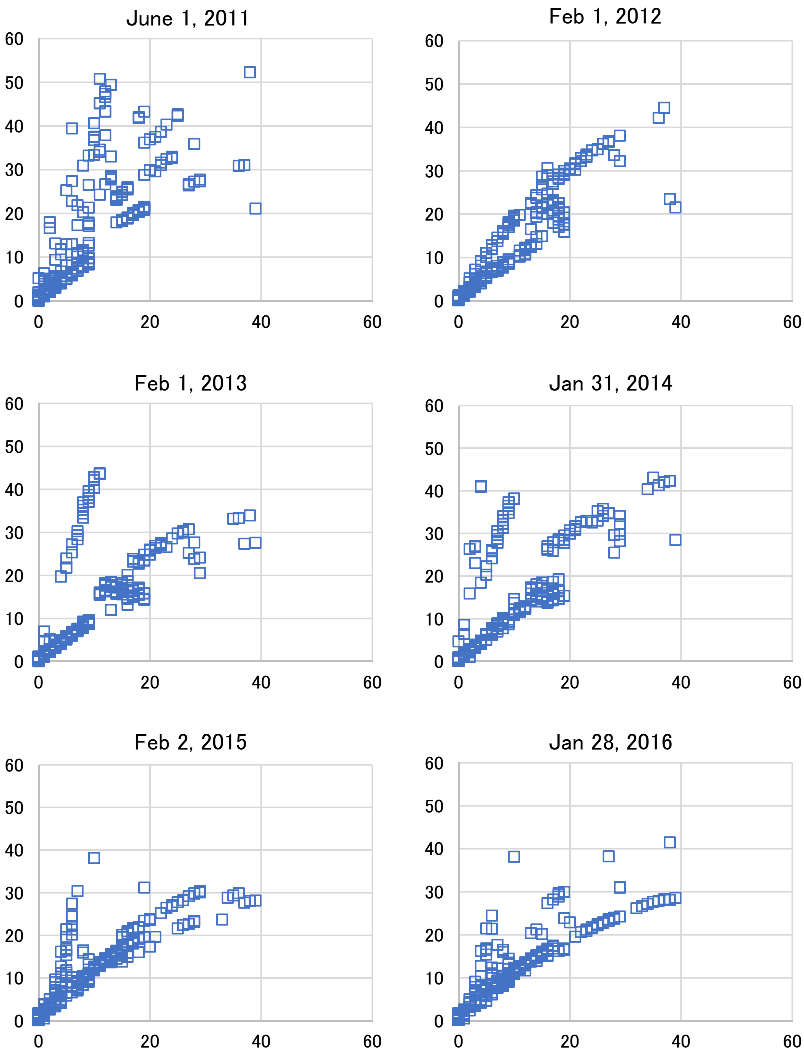
Note: The time-series evolution of the JGB yield with remaining maturities of one, five, 10, and 30 years, by order of color darkness. The data set was obtained from the Japanese Ministry of Finance (MOF) website and covers the period from February 1, 2009, to January 28, 2016. The QE period from June 2011 is divided into five subperiods: The CEbase from June 1, 2011 to January 31, 2012, the CE0 from February 1, 2012 to February 27, 2013, the QQEX from February 28, 2013 to May 31, 2013, the QQE1 from June 1, 2013 to October 30, 2014, and the QQE2 from October 31, 2014 to January 28, 2016.

Figure 2: The BoJ's monthly purchase amounts of nominal JGBs (in trillions of yen)



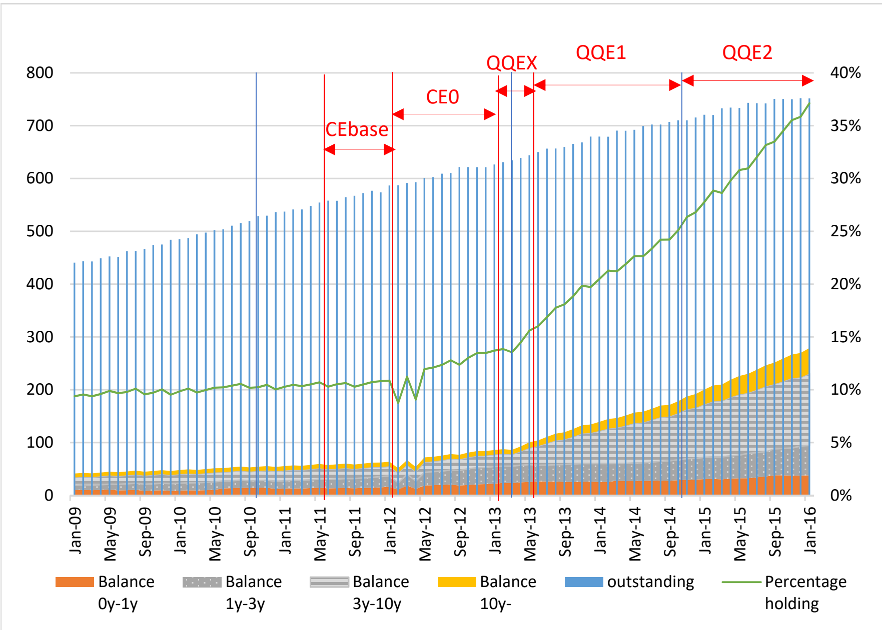
Note: The orange, dotted gray, gray-striped, and yellow areas indicate the BoJ's monthly purchase amounts of bonds with a remaining maturity of less than one year, between one and three years, between three and 10 years, and more than 10 years, respectively. We calculate these by the increments of the 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: Liquidity term structure of the bid–ask spread



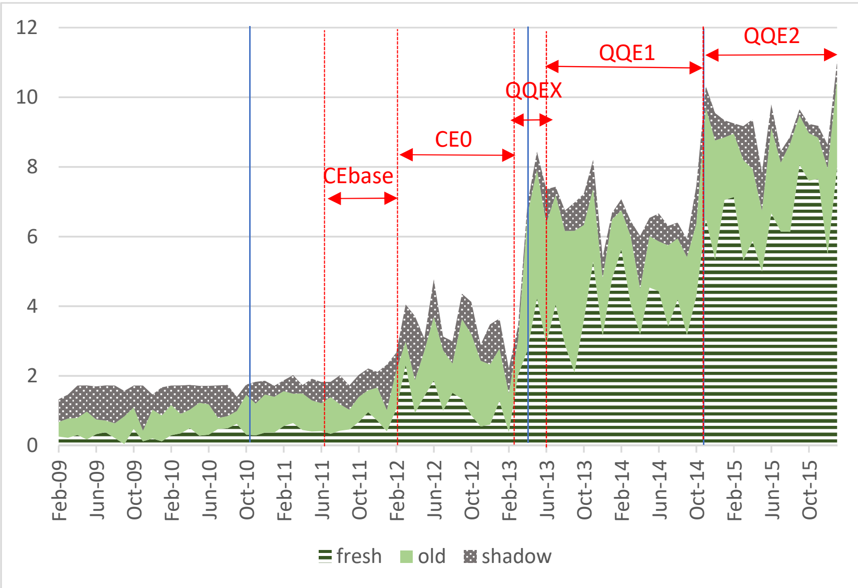
Note: This figure shows the liquidity term structure of the bid–ask spread (in basis points) for all the JGBs for six randomly selected days at about one-year intervals.

Figure 4: Outstanding amounts and the BoJ's holdings of nominal JGBs (in trillions of yen)



Note: The blue bars are the monthly outstanding amounts of nominal JGBs. The orange, dotted, 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 5: The BoJ's monthly purchase amounts of fresh, old, and shadow bonds (in trillions of yen)



Note: The green- and white-striped area indicates the BoJ's monthly purchase amounts of fresh bonds (bonds issued within one year), the pale-green area indicates those of old bonds, and the grey dotted area indicates those of shadow bonds. We calculate these areas 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.

Table 1. Summary of LSAPs

(a) The numbers of the BoJ's auction operations for each target range

	CEbase	CE0	QQEX		QQE1	QQE2	total
0–1 y	16	26	6	0–1 y	34	30	112
1–10 y	45	102	29	1–3 y	102	90	752
				3–10 y	204	180	
10+ y	8	13	8	10+ y	107	150	286
Total	69	141	43	total	447	450	1150

(b) The BoJ's total purchase amounts (in trillions of yen) of nominal JGBs for each maturity range

	CEbase	CE0	QQEX		QQE1	QQE2	
0–1 y	5.0	7.8	1.3	0–1 y	3.8	2.2	20.10
1–10 y	10.7	36.3	15.6	1–3 y	26.2	35.4	267.47
				3–10 y	70.1	73.2	
10+ y	0.8	1.3	2.1	10+ y	15.2	29.0	48.42
Total	16.5	45.4	18.9	total	115.4	139.8	335.98

(c) Average auction sizes (in billions of yen) for each maturity range

	CEbase	CE0	QQEX		QQE1	QQE2
0–1 y	310.0	310.0	210.0	0–1 y	112.6	74.0
1–10 y	237.8	362.7	536.2	1–3 y	256.4	393.3
				3–10 y	343.1	405.9
10+ y	100.0	100.0	262.5	10+ y	141.8	192.8

Note: 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 CEbase, CE0, and QQEX periods and less than one year, one to three years, three to 10 years, and more than 10 years for the first and second QQE periods, respectively. The period is divided into five subperiods: The CEbase from June 1, 2011 to January 31, 2012, the CE0 from February 1, 2012 to February 27, 2013, the QQEX from February 28, 2013 to May 31, 2013, the QQE1 from June 1, 2013 to October 30, 2014, and the QQE2 from October 31, 2014 to January 28, 2016.

Table 2. Descriptive statistics of the bid–ask spread

		0–1 year	1–3 years	3–10 years	10+ years	Entire sample
CEbase	Average	0.965	2.616	8.984	28.500	15.330
	Median	0.800	2.174	7.142	25.480	9.926
	Std. Dev.	0.604	1.624	6.232	10.009	13.644
	Observations	2924	8279	13221	17566	41990
CE0	Average	0.937	2.206	10.160	21.240	12.650
	Median	0.799	1.844	6.761	18.290	9.154
	Std. Dev.	0.538	1.549	9.560	8.291	11.055
	Observations	6140	11992	23024	29592	70748
QQEX	Average	0.662	2.100	7.120	17.310	10.050
	Median	0.600	1.852	6.618	15.110	8.940
	Std. Dev.	0.334	1.189	3.505	5.683	7.818
	Observations	1563	2671	5556	7184	16974
QQE1	Average	0.869	2.647	11.030	16.940	11.430
	Median	0.693	1.899	7.206	14.720	10.680
	Std. Dev.	0.959	2.963	9.775	6.044	9.115
	Observations	7123	15214	31557	40225	94119
QQE2	Average	0.945	2.706	8.284	18.070	10.830
	Median	0.800	2.488	7.670	16.260	9.590
	Std. Dev.	0.543	1.415	4.178	6.393	8.115
	Observations	6441	13861	28039	34151	82492

Note: This table shows the average, median, and standard deviation of the bid–ask spread (in basis points) for each remaining maturity. The period is divided into five subperiods: The CEbase from June 1, 2011 to January 31, 2012, the CE0 from February 1, 2012 to February 27, 2013, the QQEX from February 28, 2013 to May 31, 2013, the QQE1 from June 1, 2013 to October 30, 2014, and the QQE2 from October 31, 2014 to January 28, 2016.

Table 3. Descriptive statistics of the bond yield

		0–1 year	1–3 years	3–10 years	10+ years	Entire sample
CEbase	Average	13.520	15.100	55.140	162.600	15.330
	Median	12.000	14.330	49.590	167.300	9.926
	Std. Dev.	4.683	2.796	25.807	27.101	67.958
	Observations	2924	8279	13221	17566	41990
CE0	Average	10.980	10.320	40.070	147.500	12.650
	Median	10.170	10.100	34.130	153.400	9.154
	Std. Dev.	3.513	2.147	24.491	31.318	65.293
	Observations	6140	11992	23024	29592	70748
QQEX	Average	9.163	9.744	35.640	125.900	10.050
	Median	9.749	11.200	32.800	130.800	8.940
	Std. Dev.	2.664	4.432	20.861	33.463	56.870
	Observations	1563	2671	5556	7184	16974
QQE1	Average	8.530	9.044	32.920	121.800	11.430
	Median	7.999	8.834	27.720	121.600	10.680
	Std. Dev.	4.926	2.561	18.833	35.636	55.995
	Observations	7123	15214	31557	40225	94119
QQE2	Average	1.062	0.501	14.240	88.160	10.830
	Median	0.608	0.500	10.650	84.200	9.590
	Std. Dev.	2.741	2.022	11.779	33.933	45.706
	Observations	6441	13861	28039	34151	82492

Note: This table shows the average, median, and standard deviation of the bond yield (in basis points) for each remaining maturity. The period is divided into five subperiods: The CEbase from June 1, 2011 to January 31, 2012, the CE0 from February 1, 2012 to February 27, 2013, the QQEX from February 28, 2013 to May 31, 2013, the QQE1 from June 1, 2013 to October 30, 2014, and the QQE2 from October 31, 2014 to January 28, 2016.

Table 4. Differences in the bid–ask spreads for two sample periods

		CE0		QQEX		QQE1		QQE2	
0–1 y	CEbase	−0.028	**	−0.304	***	−0.096	***	−0.020	
1–3 y		−0.409	***	−0.516	***	0.033		0.090	***
3–10 y		1.177	***	−1.865	***	2.048	***	−0.702	***
10+ y		−7.184	***	−11.114	***	−11.482	***	−10.323	***
0–1 y	CE0			−0.276	***	−0.068	***	0.008	
1–3 y				−0.106	***	0.443	***	0.500	***
3–10 y				−3.042	***	0.871	***	−1.879	***
10+ y				−3.930	***	−4.298	***	−3.139	***
0–1 y	QQEX					0.208	***	0.284	***
1–3 y						0.549	***	0.606	***
3–10 y						3.913	***	1.163	***
10+ y						−0.368	***	0.792	***
0–1 y	QQE1							0.076	***
1–3 y								0.057	**
3–10 y								−2.750	***
10+ y								1.159	***

Note: 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 period is divided into five subperiods: The CEbase from June 1, 2011 to January 31, 2012, the CE0 from February 1, 2012 to February 27, 2013, the QQEX from February 28, 2013 to May 31, 2013, the QQE1 from June 1, 2013 to October 30, 2014, and the QQE2 from October 31, 2014 to January 28, 2016.

Table 5. Time-series panel regression of the changes in the bid–ask spreads

		CEbase	CE0	QQEX	QQE1	QQE2
Spotlight	Target	−0.3967	−0.0254	0.1725	0.0647	0.0059
		(−1.37)	(−0.26)	(0.37)	(0.57)	(0.04)
	Targeted the first time	−0.9702 *	−0.1639	1.9551 ***	−0.1785	−0.1161
		(−1.75)	(−0.92)	(2.92)	(−1.23)	(−0.42)
	Purchased	0.0589	0.0036	0.0031	−0.0098	−0.0398 *
		(1.38)	(0.42)	(0.10)	(−1.22)	(−1.75)
Lagged	Change in yield lagged	−0.0843	0.0116	−0.0083	−0.0326	−0.0039
		(−0.9)	(0.4)	(−0.2)	(−1.2)	(−0.09)
	Change in spread lagged	−0.4983 ***	−0.4429 ***	−0.4832 ***	−0.4561 ***	−0.4734 ***
		(−9.8)	(−9.7)	(−4.2)	(−11.4)	(−21.0)
Macro	TOPIX change	0.0117	−0.0663	0.0587	0.0039	0.0841
		(0.08)	(−1.06)	(0.79)	(0.11)	(1.54)
	US and German bond change	−0.9219	−1.8398	−1.7217	−1.3223	1.6991
		(−0.39)	(−1.34)	(−0.34)	(−0.69)	(0.89)
	JGB VIX change	1.7856 **	0.1080	−0.4615 *	0.1768	0.1117
		(2.46)	(0.70)	(−1.81)	(0.91)	(0.31)
	Fed announcement date (−)	0.0357	0.1646	0.3070	0.0477	−0.6221 ***
		(0.16)	(0.79)	(0.64)	(0.14)	(−3.51)
	Fed announcement date (+)	−0.6432	0.9432	−0.0883	−0.6024	−0.0197
		(−1.44)	(1.64)	(−0.21)	(−1.62)	(−0.07)
	ECB announcement date (−)	−1.4531 ***	0.3749 **	−0.0219	0.1404	−0.9527 ***
		(−2.66)	(2.53)	(−0.07)	(0.92)	(−2.77)
	ECB announcement date (+)	0.3902	0.1934	2.2428 **	−0.1746	−0.0838
		(0.47)	(0.79)	(2.42)	(−0.98)	(−0.17)
Newly	Newly issued (issue date)	0.0533	0.0112	0.0129	−0.0518 **	0.0042
		(1.214)	(0.560)	(0.760)	(−1.994)	(0.187)
	Newly issued (day before the issue)	0.0001	0.0286	−0.0012	−0.0024	0.0003
		(0.00)	(0.84)	(−0.05)	(−0.08)	(0.02)
	Newly issued (day after the issue)	−0.0272	−0.0715	0.0095	0.0185	−0.0243
		(−0.89)	(−1.41)	(0.54)	(0.87)	(−0.90)
Control	Remaining time to maturity	−0.1688	0.1287	−0.7356	0.0430	0.0050
		(−0.30)	(1.00)	(−0.51)	(0.32)	(0.03)
	Remaining time squared	0.0218	0.0003	0.0461	0.0003	0.0010
		(0.48)	(0.04)	(1.52)	(0.07)	(0.11)
	Observations	41798	70437	16901	93709	82143
	Adjusted R squared	0.251	0.195	0.226	0.206	0.224

Note: 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. (7). Security-level fixed effects are not shown. 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 6. Cross-sectional regression of the bid–ask spread

		CEbase		CE0		QQEX		QQE1		QQE2	
Spotlight	Target	0.3952		0.7259	**	1.0320	**	0.9020	***	0.1657	
		(1.05)		(2.09)		(2.52)		(3.01)		(1.20)	
	Targeted the first time	−1.2964	**	−0.2763		1.7345		2.1848	***	0.0418	
		(−2.43)		(−0.37)		(1.38)		(3.86)		(0.13)	
	Purchased	−0.0481		−0.1829	***	−0.0411		−0.0871	**	−0.0354	**
		(−0.73)		(−3.55)		(−1.52)		(−2.49)		(−2.21)	
Scarcity	Relative holding ratio of the bond	0.4805	***	2.0204	***	0.3870	***	1.5225	***	0.3293	***
		(2.71)		(5.47)		(4.69)		(4.72)		(3.85)	
	Substitutes relative holding ratio	3.5080	***	−1.4294	*	−0.4808	***	2.2008	*	0.4621	***
		(7.01)		(−1.65)		(−2.63)		(1.88)		(2.85)	
Control	Drop	0.5772		0.0548		0.3284		−0.4948		−0.0768	
		(0.75)		(0.05)		(1.05)		(−0.85)		(−0.53)	
	Dropped the first time	0.9506		−1.1820		0.1408		0.3904	**	−0.6511	
		(1.51)		(−1.55)		(0.20)		(2.32)		(−0.70)	
	Coupon	−0.7312	***	−1.1270	***	−0.0067		0.5545		0.2028	***
		(−2.82)		(−3.03)		(−0.07)		(1.45)		(3.63)	
	Outstanding amount	−4.3079	***	−3.4814	***	−0.9338	***	−2.8407	***	−0.1144	*
		(−11.82)		(−7.29)		(−8.32)		(−7.79)		(−1.87)	
	Remaining time to maturity	2.1679	***	1.5304	***	1.0542	***	1.0798	***	1.2146	***
		(29.83)		(10.19)		(20.92)		(9.31)		(70.41)	
	Remaining time squared	−0.0229	***	−0.0191	***	−0.0070	***	−0.0081	***	−0.0118	***
		(−11.49)		(−5.41)		(−5.00)		(−3.43)		(−25.60)	
	Observations	41990		70748		16974		94119		82492	
	Adjusted R squared	0.836		0.680		0.907		0.907		0.654	

Note: This table presents the results for the cross-sectional regression of the bid–ask spread for the five periods. The dependent variable is the bid–ask spread in basis points and the regression equation is presented in Eq. (8). The daily time dummies are not shown. 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 double cluster-robust standard errors. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***) levels.

Table 7. Impact of the three life stages of the term structure on spread

		CEbase	CE0	QQEX	QQE1	QQE2
Spotlight	Target	0.2860	0.5496 *	1.0204 **	0.7178 ***	0.1550
		(0.77)	(1.82)	(2.49)	(2.66)	(1.12)
	Targeted the first time	−0.5790	0.4861	1.8696	2.3056 ***	0.0264
		(−1.27)	(0.73)	(1.51)	(4.26)	(0.08)
	Purchased	−0.0170	−0.1455 ***	−0.0292	−0.0619 **	−0.0368 **
		(−0.25)	(−2.75)	(−1.08)	(−2.07)	(−2.50)
Scarcity	Relative holding ratio of the bond	0.4059 **	1.9919 ***	0.3758 ***	1.4238 ***	0.3481 ***
		(2.23)	(5.40)	(4.45)	(4.56)	(4.06)
	Substitutes relative holding ratio	3.4767 ***	−1.2790	−0.4336 **	2.8587 **	0.3207 *
		(6.66)	(−1.61)	(−2.41)	(2.49)	(1.95)
Life stage	Old bond dummy	1.1088 ***	1.0905 **	0.3897 **	−0.3438	−0.1422
		(2.60)	(2.30)	(2.02)	(−0.92)	(−1.59)
	Shadow bond dummy	1.3155 **	1.9564 **	0.5305 **	3.3750 ***	0.2380 **
		(2.52)	(2.47)	(2.34)	(3.83)	(1.98)
Control	Drop	0.3739	−0.0929	0.3295	0.0297	−0.0242
		(0.48)	(−0.09)	(1.09)	(0.05)	(−0.16)
	Dropped the first time	1.1117	−0.9454	0.1673	0.3886	−0.6552
		(1.60)	(−1.19)	(0.24)	(1.26)	(−0.71)
	Coupon	−0.8355 **	−1.4187 ***	−0.1006	−0.1265	0.1384 *
		(−3.25)	(−3.55)	(−0.93)	(−0.28)	(2.27)
	Outstanding amount	−4.2058 ***	−3.2437 ***	−0.8957 ***	−2.1296 ***	−0.0451
		(−11.67)	(−7.28)	(−8.45)	(−6.59)	(−0.80)
	Remaining time to maturity	2.173 ***	1.621 ***	1.072 ***	1.400 ***	1.238 ***
		(27.27)	(11.46)	(18.98)	(9.82)	(69.85)
	Remaining time squared	−0.023 ***	−0.021 ***	−0.007 ***	−0.014 ***	−0.012 ***
		(−11.88)	(−5.94)	(−4.85)	(−4.93)	(−26.14)
	Observations	41990	70748	16974	94119	82492
	Adjusted R squared	0.837	0.682	0.908	0.673	0.840

Note: This table presents the results for the cross-sectional regression of the bid–ask spread with two dummies of the liquidity term structure. The dependent variable is the bid–ask spread in basis points and the regression equation is presented in Eq. (9). The daily time dummies are not shown. 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 8. Impact of the three bond life stages of term structure on the spread through the spotlight and scarcity effects

		CEbase		CE0		QQEX		QQE1		QQE2	
Spotlight	Target	0.6242		0.4364		0.9665	***	0.0961		0.2132	
		(1.44)		(1.42)		(2.78)		(0.50)		(1.20)	
	Targeted the first time	−0.8073		0.2212		0.9754		0.1393		−0.4618	
		(−1.61)		(0.40)		(1.51)		(0.35)		(−1.42)	
	Purchased	0.0165		0.0121		−0.0293	**	0.0187		−0.0286	*
		(0.36)		(0.39)		(−2.25)		(0.93)		(−1.93)	
Scarcity	Relative holding ratio of the bond	−1.0578	**	−0.6436	***	−0.2093	**	−0.2208		−0.1006	
		(−2.31)		(−3.19)		(−2.43)		(−1.16)		(−1.20)	
	Substitutes relative holding ratio	7.4149	***	3.1733	***	1.0503	***	4.3544	***	0.6366	*
		(10.58)		(3.92)		(4.90)		(4.74)		(1.84)	
Life stage	Old bond dummy	2.9632	***	1.0528		1.0296	***	0.4335		−0.2040	
		(4.80)		(1.58)		(3.79)		(0.63)		(−0.52)	
Cross term	Target × Old	−0.5408	*	−0.1640		0.0161		0.0050		−0.1006	
with		(−1.7)		(−0.6)		(0.0)		(0.0)		(−0.6)	
Old	Targeted the first time × Old	NA		NA		9.2669	***	NA		NA	
						(11.5)					
	Purchased × Old	−0.0107		−0.3614	***	−0.0253		0.1691	***	−0.0277	
		(−0.12)		(−3.79)		(−0.45)		(2.89)		(−0.42)	
	Relative holding ratio of the bond	1.5702	***	3.2716	***	0.4784	***	0.9974	***	0.2701	**
	× Old	(2.92)		(4.57)		(3.37)		(2.61)		(2.36)	
	Substitutes relative holding ratio	−2.7195	***	−2.1793	***	−0.8797	***	−1.8456	***	−0.1733	
	× Old	(−4.48)		(−2.78)		(−3.52)		(−2.76)		(−0.49)	
Life stage	Shadow bond dummy	8.6958	***	8.3974	***	2.0923	***	−0.1166		−0.0985	
		(9.29)		(5.40)		(6.28)		(−0.08)		(−0.22)	
Cross term	Target × Shadow	−0.2692		0.8202	*	−0.0006		1.4637	***	−0.0322	
with		(−1.10)		(1.79)		(0.00)		(3.47)		(−0.15)	
Shadow	Targeted the first time × Shadow	NA		−3.3587	***	−1.6824	*	NA		NA	
				(−2.98)		(−1.78)					
	Purchased × Shadow	0.1327		−0.2452	***	0.0788		−0.4091	*	−0.0801	*
		(1.24)		(−2.60)		(1.05)		(−1.77)		(−1.88)	
	Relative holding ratio of the bond	1.5807	***	2.4932	***	0.7205	***	3.2723	***	0.8531	***
	× Shadow	(3.23)		(5.65)		(5.13)		(4.40)		(4.55)	
	Substitutes relative holding ratio	−7.6603	***	−7.2424	***	−1.9556	***	−0.1905		−0.4287	
	× Shadow	(−10.47)		(−7.47)		(−8.10)		(−0.12)		(−1.03)	
Control	Drop	0.0788		0.3743		0.3402		−0.1713		−0.1034	
		(0.14)		(0.41)		(1.16)		(−0.21)		(−0.67)	
	Dropped the first time	0.1262		−0.5687		−0.1177		0.2848		−0.5538	
		(0.29)		(−0.91)		(−0.18)		(1.13)		(−0.59)	
	Coupon	−0.4511	**	−0.9061	***	0.0321		−0.5935		0.1012	
		(−2.44)		(−2.94)		(0.34)		(−1.21)		(1.53)	
	Outstanding amount	−3.5056	***	−2.4040	***	−0.6596	***	−2.2351	***	−0.0139	
		(−10.05)		(−6.03)		(−6.21)		(−6.51)		(−0.23)	
	Remaining time to maturity	2.1562	***	1.5942	***	1.1001	***	1.4822	***	1.2449	***
		(29.63)		(13.33)		(20.60)		(10.81)		(70.13)	
	Remaining time squared	−0.0203	***	−0.0169	***	−0.0074	***	−0.0160	***	−0.0124	***
		(−12.11)		(−6.63)		(−5.21)		(−5.59)		(−26.24)	
	Observations	41990		70748		16974		94119		82492	
	Adjusted R squared	0.846		0.707		0.910		0.687		0.841	

Note: This table presents the results for the cross-sectional regression of the spread with two dummies of the liquidity term structure and their cross terms with the spotlight and scarcity effects. The dependent variable is the bid–ask spread in basis points and the regression equation is presented in Eq. (10). The daily time dummies are not shown. 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 9. Time-series panel regression of changes in yields

		CEbase		CE0		QQEX		QQE1		QQE2	
Spotlight	Target	−0.4248	***	−0.1520		−0.5660		−0.3092	***	−0.3352	**
		(−4.06)		(−1.01)		(−0.76)		(−3.67)		(−2.35)	
	Targeted the first time	−0.5280	***	−0.2484		−1.0090		0.0873		0.0443	
		(−2.71)		(−1.59)		(−0.62)		(0.37)		(0.21)	
	Purchased	0.0339	*	0.0097		0.0324		0.0041		0.0094	
		(1.72)		(0.79)		(0.68)		(0.86)		(1.28)	
Lagged	Change in yield lagged	0.0869	*	−0.0725		0.1095		−0.3678	***	−0.1259	**
		(1.9)		(−1.1)		(1.1)		(−2.6)		(−2.55)	
	Svensson fitting error lagged	−0.1897	***	−0.0583	**	−0.0602	**	−0.0531	***	−0.0149	**
		(−5.8)		(−2.5)		(−2.3)		(−3.3)		(−2.0)	
Macro	TOPIX change	0.3893	***	0.2528	***	0.3008	**	0.1738	***	−0.0073	
		(6.25)		(4.56)		(2.00)		(3.79)		(−0.13)	
	US and German bond change	4.6867	***	8.2759	***	16.3733	**	8.1378	***	14.5741	***
		(2.93)		(4.97)		(2.33)		(4.27)		(5.65)	
	USD/JPY cross-currency swap change	−0.0412		0.0519		−0.2077		−0.0960	*	−0.0435	
		(−1.58)		(1.56)		(−1.23)		(−1.70)		(−0.70)	
	Fed announcement date (−)	−0.6075	***	0.4899		−1.4742	*	0.5405		0.1275	
		(−4.57)		(0.99)		(−1.70)		(1.43)		(0.25)	
	Fed announcement date (+)	−0.6397	***	−0.7687	**	−1.3049	**	−0.3168		−1.1439	**
		(−3.10)		(−2.34)		(−2.43)		(−0.91)		(−2.12)	
	ECB announcement date (−)	−0.5427		−0.4798	*	−2.3549	***	0.4714	**	0.2224	
		(−1.60)		(−1.72)		(−4.75)		(2.57)		(0.62)	
	ECB announcement date (+)	0.5101	*	0.0386		2.1457	***	0.0030		0.0725	
		(1.83)		(0.20)		(2.93)		(0.02)		(0.11)	
Newly	Newly issued (issue date)	−0.038	**	0.024	*	−0.035		0.007		0.018	
		(−2.162)		(1.881)		(−0.879)		(0.505)		(0.923)	
	Newly issued (day before the issue)	−0.012		−0.010		0.018		0.031	***	0.019	
		(−0.68)		(−0.71)		(0.37)		(2.87)		(1.24)	
	Newly issued (day after the issue)	−0.025		0.022	**	−0.024		−0.004		0.012	
		(−1.17)		(2.13)		(−0.63)		(−0.37)		(0.81)	
Control	Drop	−0.7298	***	0.0178		−0.5993		−0.1542	*	−0.1118	
		(−3.86)		(0.14)		(−0.91)		(−1.77)		(−0.44)	
	Dropped the first time	−0.4271	**	−0.1235		−1.3210	*	−0.5747	**	0.0057	
		(−2.47)		(−0.60)		(−1.92)		(−2.41)		(0.01)	
	Program announcement	0.0816		−0.2126		−8.3111	***	NA		−0.8463	**
		(0.63)		(−0.70)		(−16.11)				(−2.12)	
	Remaining time to maturity	0.050		0.367		−6.108	**	0.048		0.064	
		(0.16)		(1.61)		(−2.25)		(0.40)		(0.38)	
	Remaining time squared	−0.007		−0.008		−0.143		−0.002		−0.002	
		(−0.74)		(−1.22)		(−1.20)		(−0.53)		(−0.26)	
	Observations	41798		70437		16901		93709		82143	
	Adjusted R squared	0.229		0.166		0.214		0.176		0.111	

Note: This table presents the results for the regression of the changes in the yields for the five subperiods. The dependent variable is the change in the daily yield in basis points and the regression equation is presented in Eq. (11). Security-level fixed effects are not shown. 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 10. Cross-sectional regression of the bond yield

		CEbase		CE0		QQEX		QQE1		QQE2	
Spotlight	Target	−1.6936	**	−2.6420	***	−4.5931	***	−2.7216	***	−1.7969	***
		(−2.22)		(−3.97)		(−2.60)		(−4.96)		(−3.52)	
	Targeted the first time	−1.0314		−2.1175	*	−11.4678	**	−3.3392	**	0.0403	
		(−1.09)		(−1.74)		(−2.28)		(−2.02)		(0.02)	
	Purchased	0.8552	***	0.0597		0.0044		−0.0814		0.2309	***
		(3.23)		(0.70)		(0.04)		(−1.01)		(2.67)	
Scarcity	Relative holding ratio of the bond	−0.3689		−0.9606	*	−1.4373	**	−1.1850	*	−0.2734	
		(−0.72)		(−1.84)		(−2.55)		(−1.91)		(−0.38)	
	Substitutes relative holding ratio	11.6048	***	14.7415	***	11.3215	***	−14.6826	***	−16.6209	***
		(8.95)		(9.38)		(6.14)		(−12.17)		(−14.99)	
Control	Drop	−5.5307	***	−4.1139	**	−6.2628	***	−2.8297	*	−5.0957	**
		(−3.36)		(−2.48)		(−2.70)		(−1.65)		(−2.53)	
	Dropped the first time	−0.2657		−2.4901	*	0.7607		1.4632		0.4831	
		(−0.08)		(−1.77)		(0.21)		(0.46)		(0.21)	
	Coupon	−0.3986		−1.4212		−1.8383	**	−1.9262	*	−1.0972	
		(−0.42)		(−1.38)		(−2.13)		(−1.93)		(−1.51)	
	Outstanding amount	−1.8406	**	−3.1875	***	−3.1105	***	−3.7391	***	−0.8458	
		(−2.26)		(−3.68)		(−3.22)		(−4.94)		(−1.22)	
	Remaining time to maturity	14.0584	***	13.2165	***	11.1328	***	8.3889	***	5.6902	***
		(71.64)		(43.50)		(28.99)		(36.22)		(27.26)	
	Remaining time squared	−0.2023	***	−0.1725	***	−0.1417	***	−0.0915	***	−0.0304	***
		(−41.33)		(−22.00)		(−13.41)		(−12.47)		(−4.53)	
	Observations	41990		70748		16974		94119		82492	
	Adjusted R squared	0.986		0.977		0.962		0.962		0.970	

Note: This table presents the results for the cross-sectional regression of the yield for the five periods. The dependent variable is the yield in basis points and the regression equation is presented in Eq. (12). The daily time dummies are not shown. 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 11. Impact of the three stages of term structure on bond yield

		CEbase		CE0		QQEX		QQE1		QQE2	
Spotlight	Target	−1.4845	*	−3.1813	***	−4.9507	***	−2.6984	***	−1.9019	***
		(−1.96)		(−4.96)		(−2.83)		(−4.96)		(−3.63)	
	Targeted the first time	−2.8061	***	−3.4730	***	−11.7277	**	−5.0803	***	−2.6226	*
		(−4.32)		(−3.11)		(−2.07)		(−3.00)		(−1.65)	
	Purchased	0.7903	***	0.0609		0.0810		−0.1494	**	0.0216	
		(2.85)		(0.77)		(0.62)		(−2.18)		(0.35)	
Scarcity	Relative holding ratio of the bond	−0.2214		−1.0495	**	−1.2139	**	−1.2274	**	−0.0712	
		(−0.44)		(−2.06)		(−2.00)		(−1.98)		(−0.10)	
	Substitutes relative holding ratio	11.8628	***	16.2549	***	13.4541	***	−15.0245	***	−18.7780	***
		(8.61)		(10.70)		(7.85)		(−12.23)		(−16.45)	
Life stage	Old bond dummy	−2.7761	**	−2.9388	**	−1.6054		−2.4957	*	−5.2087	***
		(−2.31)		(−2.34)		(−0.86)		(−1.75)		(−4.11)	
	Shadow bond dummy	−2.8025	*	1.8402		5.6621	***	−2.8259		−1.0735	
		(−1.86)		(1.01)		(2.77)		(−1.55)		(−0.79)	
Control	Drop	−5.0233	***	−3.8570	**	−4.8712	**	−2.7236		−3.9908	**
		(−3.09)		(−2.33)		(−1.98)		(−1.64)		(−2.21)	
	Dropped the first time	−0.5915		−2.7410	*	0.1784		1.1910		−0.7462	
		(−0.19)		(−1.92)		(0.07)		(0.38)		(−0.35)	
	Coupon	−0.1803		−1.7609		−2.9768	**	−1.4407		−1.0784	
		(−0.19)		(−1.41)		(−2.59)		(−1.28)		(−1.26)	
	Outstanding amount	−2.0008	*	−2.3425	**	−1.4440		−3.8661	***	−0.0273	
		(−2.36)		(−2.69)		(−1.51)		(−5.16)		(−0.04)	
	Remaining time to maturity	14.092	***	13.761	***	12.040	***	8.344	***	5.911	***
		(56.09)		(38.53)		(29.15)		(31.07)		(26.56)	
	Remaining time squared	−0.203	***	−0.183	***	−0.159	***	−0.091	***	−0.036	***
		(−37.51)		(−21.91)		(−14.97)		(−11.66)		(−5.36)	
	Observations	41990		70748		16974		94119		82492	
	Adjusted R squared	0.986		0.978		0.964		0.970		0.967	

Note: This table presents the results for the cross-sectional regression of the bond yield with two dummies of the liquidity term structure. The dependent variable is the yield in basis points and the regressors are the same as in Eq. (9). The daily time dummies are not shown. 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 12. Impact of the term structure on yield through the spotlight and scarcity effects for the three bond life stages

		CEbase		CE0		QQEX		QQE1		QQE2	
Spotlight	Target	0.0642		−1.5925	***	−3.9953	**	−0.8712	**	−0.8741	*
		(0.10)		(−2.91)		(−2.36)		(−2.19)		(−1.91)	
	Targeted the first time	−1.9192	**	−1.6809	*	−8.3201	**	−2.1030		−0.5687	
		(−2.32)		(−1.84)		(−2.21)		(−1.06)		(−0.41)	
	Purchased	−0.3964	**	−0.1354	**	−0.1268	**	−0.2409	***	0.0374	
		(−2.49)		(−2.37)		(−2.01)		(−3.56)		(0.51)	
Scarcity	Relative holding ratio of the bond	5.2198	***	3.1120	***	3.4527	***	0.6544		1.5951	**
		(3.48)		(5.62)		(4.29)		(0.63)		(2.44)	
	Substitutes relative holding ratio	6.8031	***	9.4723	***	5.4321	**	−20.6204	***	−31.0883	***
		(3.56)		(5.82)		(2.44)		(−7.13)		(−8.17)	
Life stage	Old bond dummy	−3.0083		−0.7151		0.0432		−3.6409		−18.0194	***
		(−1.53)		(−0.41)		(0.01)		(−1.06)		(−3.73)	
Cross term	Target × Old	−3.0672	***	−2.4418	***	−0.6652		−1.1017	***	−0.7640	
with		(−4.0)		(−3.6)		(−0.5)		(−2.7)		(−1.6)	
Old	Targeted the first time × Old	NA		NA		−28.5269	***	NA		NA	
						(−7.9)					
	Purchased × Old	2.3025	***	0.5727	***	0.1757		−0.1819		−0.4539	**
		(4.18)		(2.91)		(0.62)		(−1.21)		(−2.32)	
	Relative holding ratio of the bond	−5.1953	***	−4.9860	***	−2.6321	*	0.0273		1.1570	
	× Old	(−3.21)		(−4.95)		(−1.91)		(0.02)		(0.78)	
	Substitutes relative holding ratio	1.5489		0.8366		−2.4615		0.4842		10.3908	**
	× Old	(0.73)		(0.40)		(−0.76)		(0.16)		(2.43)	
Life stage	Shadow bond dummy	−14.2984	***	−10.4237	***	−4.7100		−13.8675	***	−13.3044	***
		(−4.55)		(−3.64)		(−1.34)		(−3.15)		(−2.76)	
Cross term	Target × Shadow	−1.8257	***	−2.8269	***	−1.4814	**	−2.8206	***	−1.4230	***
with		(−3.14)		(−4.42)		(−2.05)		(−6.31)		(−3.33)	
Shadow	Targeted the first time × Shadow	NA		−5.9714		7.1551	***	NA		NA	
				(−1.38)		(2.61)					
	Purchased × Shadow	0.7229	**	−0.1513		0.1528		0.3185	*	0.2282	
		(1.98)		(−1.01)		(0.37)		(1.79)		(0.96)	
	Relative holding ratio of the bond	−5.8521	***	−3.9059	***	−5.4797	***	−4.4433	***	−4.5498	***
	× Shadow	(−3.68)		(−5.02)		(−4.97)		(−2.96)		(−3.43)	
	Substitutes relative holding ratio	12.8979	***	13.0348	***	12.9381	***	15.5155	***	15.0151	***
	× Shadow	(5.72)		(7.90)		(5.52)		(4.37)		(3.76)	
Control	Drop	−4.6783	***	−4.8825	***	−5.2934	**	−2.1489		−2.9973	*
		(−2.74)		(−3.29)		(−2.21)		(−1.30)		(−1.70)	
	Dropped the first time	0.4081		−4.0158	***	2.5881		0.7383		−0.6175	
		(0.11)		(−2.78)		(0.76)		(0.21)		(−0.31)	
	Coupon	−0.6886		−2.7678	***	−4.3313	***	−2.3312	**	−0.8016	
		(−0.82)		(−2.60)		(−3.97)		(−1.99)		(−0.88)	
	Outstanding amount	−3.0378	***	−4.0058	***	−3.3989	***	−5.2003	***	−0.2617	
		(−3.63)		(−5.20)		(−3.86)		(−7.02)		(−0.41)	
	Remaining time to maturity	14.2324	***	13.8512	***	11.9203	***	8.4093	***	5.9390	***
		(51.58)		(41.89)		(32.19)		(30.83)		(27.18)	
	Remaining time squared	−0.2107	***	−0.1921	***	−0.1631	***	−0.0953	***	−0.0370	***
		(−32.20)		(−24.78)		(−17.28)		(−12.32)		(−5.73)	
	Observations	41990		70748		16974		94119		82492	
	Adjusted R squared	0.9873		0.9811		0.9674		0.9720		0.9679	

Note: This table presents the results for the cross-sectional regression of the bond yield with two dummies of the liquidity term structure and their cross terms with the spotlight and scarcity effects. The dependent variable is the yield in basis points and the regressors are the same as in Eq. (10). The daily time dummies are not shown. 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.