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Quantitative Easing and Liquidity in the Japanese Government Bond Market

Kentaro Iwatsubo* and Tomoki Taishi**

Abstract

The "Quantitative and Qualitative Monetary Easing" enacted immediately after the inauguration of Bank of Japan Governor Kuroda brought violent fluctuations in the prices of government bonds and deteriorated market liquidity. Does a central bank's government bond purchasing policy generally reduce market liquidity? Do conditions exist that can prevent this decrease? This study analyzes how the Bank of Japan's purchasing policy changes influenced market liquidity. The results reveal that three specific policy changes contributed significantly to improving market liquidity: 1) increased purchasing frequency; 2) a decrease in the purchase amount per transaction; and 3) reduced variability in the purchase amounts. These policy changes facilitated investors' purchase schedule expectations and helped reduce market uncertainty. The evidence supports the theory that the effect of government bond purchasing policy on market liquidity depends on the market's informational environment.

Keywords: Monetary Policy; Quantitative Easing; Liquidity; Government Bond
JEL classification: G14

***** Professor, Graduate School of Economics, Kobe University (E-mail: iwatsubo@econ.kobe-u.ac.jp)
****** Manager, Market Operations, Osaka Exchange, Inc. (E-mail: t-taishi@jpx.co.jp)

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1. Introduction

In April 2013, newly inaugurated Bank of Japan Governor Kuroda accelerated the quantitative easing program and initiated the purchase of long-term government bonds. This was called the "Quantitative and Qualitative Monetary Easing (QQE)." Even though the Japanese financial market responded strongly to this monetary easing, the government bond market recorded historically violent fluctuations. Rates on mid-term Japanese government bonds (JGBs), such as two-year and five-year bonds, rose and then slowly decreased over time. Rates on long-term (10-year) and super long-term (20-year) JGBs fell briefly then rose again. The market was surprised to see that the significant purchases of government bonds led to a decrease in bond prices (i.e., a rise in interest rates) rather than an increase (i.e., a decrease in interest rates). In response to the increases in market rates, banks raised the prime lending rates to compensate, meaning that the monetary conditions tightened rather than loosened for a short period of time (Figure 1).

In addition, the implied volatility calculated from option prices of JGBs rose significantly (Figure 2). The violent fluctuations in government bond prices continued from April into May, during which the circuit breaker in the JGB futures market was triggered five times in mid-April and further three times in May.

Possible side effects of large-scale government bond purchasing have been addressed by many academician and central bankers. Former Federal Reserve Board Chairman Ben Bernanke stated in his Jackson Hole speech that "if the Federal Reserve became too dominant a buyer in a market, trading among private agents could dry up, degrading liquidity and price discovery" (Bernanke, 2012).

Since the introduction of monetary easing, the Bank of Japan's bond holdings have exceeded giant government bond holders, such as life and non-life insurance firms, due to their rapid purchasing, resulting in a skewed bond distribution with a focus on 5- , 10- , 20- , and 30-year newly issued bonds. Accordingly, the market participants became concerned over the possible lack of floating government bonds in the market.

In general, does outright purchasing of government bonds by financial authorities deteriorate market liquidity? Do conditions exist that can prevent this decrease? During and post the second phase of the QQE policy, announced in October 2014, no confusion was evident, nor was any anxiety around liquidity apparent during the first phase of the April 2013 monetary easing. What was the difference?

While the motives and effectiveness of large-scale asset purchase programs have been intensely debated, the effect of these trades on market quality has received much less attention. Studies from the United States and European countries are split into two views: the theory that a purchasing policy has a negative effect on market liquidity (Harvey and Huang, 2002;

Andersson, 2010; Inoue, 1999) and the theory that it improves market liquidity (Pasquariello, et al., 2014; Brunetti et al., 2010; Christensen and Gillan, 2014). A consensus has not been reached on this issue.

In this study, we show that the large change in the Bank of Japan's purchasing policy, since the start of the monetary easing in April 2013, had an improved influence on market liquidity in the government bond market, as evidenced by the decrease in quote spreads and Amihud's (2002) *ILLIQ*. The purchasing policy brought about three specific changes: 1) an increase in the frequency of purchases; 2) a decrease in the purchase amount per transaction; and 3) a decrease in the variability in the purchase amounts when purchased multiple times in one day. We argue that these types of policy changes eased investors' forecast on the purchasing schedule and helped reduce market uncertainty. We find a significant rise in the adverse selection component of the effective spread in response to the large-scale government bond purchases right after the start of the QQE, but the impact gradually decreases and becomes negative as the purchasing policy changes. The model free implied volatility also shows a similar pattern. Together with the downward trend of the dispersion of the JGB yield forecasts among market participants, these pieces of evidence support the theory that central banks' communication and transparency play a significant role in the large-scale government bond purchases in terms of market liquidity.

The rest of the paper is organized as follows. Section 2 provides a brief literature review and a theoretical motivation for asymmetric information frameworks. Section 3 details the execution of government bond purchases included in the QQE and Section 4 describes the liquidity measures. Section 5 presents the empirical strategy and results. Section 6 discusses the endogeneity issues and Section 7 concludes the paper.

2. Literature Review and Hypotheses

Although numerous studies have examined how open market operations (hereafter, OMOs), a monetary policy used by financial authorities, affect asset value and the macroeconomy, few studies have investigated its influence on financial market liquidity. Harvey and Huang's (2002) research appears to be the earliest study on the subject. Using intraday data on government bond prices from 1982 to 1988, they show that the OMOs of the United States increased the volatility of government bond prices. In subsequent studies, Andersson (2010) confirms a strong upsurge in intraday bond market volatility at the time of the release of the monetary policy decisions by the Federal Reserve Board, while Inoue (1999) discovers that Japan's OMOs increased the trade volume in the government bond market and the volatility of government bond prices.

However, using data covering 2001 to 2007, Pasquariello et al. (2014) show that the OMOs of the United States lowered the bid-ask spread and question the results of previous studies claiming that monetary policies worsens market liquidity. In the paper, Pasquariello et al. (2014) focus on the fact that FRB Chairman Alan Greenspan has made the FOMC increasingly transparent by announcing the monetary policy intentions and disclosing the federal funds target rate to the public. This change made OMOs virtually uninformative about the Federal Reserve's future monetary policy stance.

Among the recent growing literature on the large-scale asset purchase programs (LSAP), Kandrac and Schlusche (2013) find no significant liquidity effects associated with Treasury purchases. In contrast, Christensen and Gillan (2014) analyze the effect the Treasury inflation-protected securities (TIPS) purchases, included in the Federal Reserve Board Q2 program, had on the functioning of the market for TIPS and the related market for inflation swaps, and find that the liquidity premium is reduced due to the TIPS purchase.

In this way, it has not been settled whether OMOs worsen or improve government bond market liquidity. First, let us briefly explain the theory that OMOs reduce market liquidity by following Chari (2007). The basis of this theory is the adverse selection model, which is used even in studies on central bank intervention in foreign exchange markets (Bhattacharya and Weller, 1997; Naranjo and Nimalendran, 2000).

In the microstructure model with strategic informed traders, Chari (2007) assumes that central banks are informed insiders since they have an informational advantage about the fundamentals of government bond prices (Bhattacharya and Weller, 1997). Furthermore, central banks have utility functions different from standard profit maximizing agents in that they can choose to incur losses on their intervention operations. In doing so, central banks weigh the expected cost of their bond transactions against their success in achieving target objectives. On the other hand, rational speculators (i.e., strategic informed traders) in the government bond market also have private information with respect to central bank objectives.

Furthermore, the following two conditions are set so that information may differ across participants in the market when central banks intervene (Kyle, 1985; Bhattacharya and Speigel, 1991). First, central banks and speculators as a group can differ in their interpretation of the fundamentals. Second, individual traders' private signals about the fundamentals may differ across traders. These two effects can lead to an increase in market uncertainty if the target price implied by the intervention signal is not consistent with the fundamentals, causing speculators facing the central bank's transactions to trade more cautiously. As a result, uncertainty on the future prices increases and market liquidity worsens. The uncertainty is especially intensified when central bank interventions are unexpected. In such case, bid-ask spreads will increase due to adverse selection risk and price volatility also increases.

Conversely, the theoretical model developed by Pasquariello et al. (2014) shows that the

OMOs improve market liquidity and the magnitude of this impact depends on the market's informational environment. The critical assumption of this theory is that, even though central banks are informed traders facing a trade-off between policy motives (a non-public and uninformed price target) and the expected cost of interventions, there is no information related to the fundamentals in the OMOs. The reason is that they already release their monetary policy decisions and policy details to the market before conducting OMOs. Therefore, the central banks' OMOs mitigate adverse selection concerns for market makers because they are noise trades and thus induce speculators to trade more aggressively on their private signals, reducing uncertainty about future prices. Consequently, price volatility decreases and the bid-ask spread narrows.

The essential difference in assumptions between the two competing theories is whether OMOs have any information on fundamentals. Japanese experience allows us to test these theories since the Bank of Japan changed their JGB purchasing policy to enable traders to forecast the timing and scale of OMOs and estimate fundamentals easily following the reduced market liquidity experienced during the April 2013 monetary easing. The Bank of Japan made their interventions more transparent by pre-announcing the monthly rough schedule of purchases, increasing the frequency of trades and decreasing the purchase amount per transaction. Therefore, we expect that government bond purchases do not worsen or even improve market liquidity after the Bank of Japan changed their policy, as the theory by Pasquariello et al. (2014) predicts.

3. Changes in the Bank of Japan's Outright Purchasing Policy

With the aim of overcoming deflation that has lasted for nearly 15 years, the Bank of Japan entered a new phase of monetary easing in terms of both quantity and quality in April 2013. It began to double the monetary base and the amounts outstanding of JGBs as well as exchange-traded funds (ETFs) in two years, and more than double the average remaining maturity of JGB purchases. The Bank of Japan purchased JGBs from financial institutions in the secondary market so that their amount outstanding increased at an annual rate of about 50 trillion yen[1]. In addition, the average remaining maturity of the Bank's JGB purchases was extended from slightly less than three years to about seven years - equivalent to the average maturity of the amount outstanding of JGBs issued.

However, the massive JGB purchases increased price volatility and worsened market liquidity. The Bank of Japan responded to the market turbulence by changing the rate of its

[1] The Bank of Japan increased the amount of purchases of JGBs at an annual rate of about 80 trillion yen at the start of the second phase of the QQE policy announced in October 2014.

purchases of government bonds. It increased the frequency of its purchases and lowered the purchase amount per transaction. Table 1 shows that through these measures, the purchase amount per transaction fell steadily from April 2014. The average number of purchases per day was fixed at 2.6, the number of days on which bonds were purchased in a month at 10, and the total number purchases in one month at 26 after June. Another apparent characteristic is that the variability in the purchasing amount decreased then leveled off in cases where there were multiple purchases in one day.

Furthermore, the Bank of Japan began to announce the monthly purchasing rate ex ante. Although the detailed schedule of the Bank of Japan's auctions is not disclosed in advance, a broad pattern has been shared with market participants.

The following is an example of actual business procedures of OMOs. At 10:10 in the morning, the Bank of Japan offers outright purchases of JBGs to eligible counterparties. Around noon on the same day, it decides on the successful bids for the purchase and notifies the bidders of the results on the total amounts of the bids, amounts of successful bids, and the average successful bid rate via the Bank of Japan's and others' websites. The purchases are executed generally two business days after the auction day.

We call the day when the target bond for outright purchasing and the purchase amount are announced, "auction day," and the day when the government bond purchase is executed, "settlement day." Since all the information about bond purchasing is revealed on the auction days, it is expected that the impact on market liquidity occurs only on the auction days.

Since the frequency of OMOs has recently increased, it is often the case that the auction day of new purchases coincides with the settlement day of the previous purchases. During the sample period from April 4, 2013, to June 30, 2014, there are 307 business days. Among these days, 74 days are when the auction day and the settlement day coincide.

4. Data

We measure liquidity using bid-ask spreads, effective spreads, one-minute realized spreads, one-minute adverse selection, and Amihud's (2002) *ILLIQ*.

Although the intraday data on the prices of the JGB futures traded on stock exchanges are available, the intraday price data on over-the-counter trading of active JGBs (spot) are not wholly available in Japan. Among various OTC brokers dealing with JGBs, the biggest broker, Japan Bond Trading CO., Ltd. (BB), discloses only execution prices and yields, which makes it impossible to measure liquidity. As an alternative to the broker's data, we use intraday data from Tradeweb, which is one of the top JGB brokers, operating electronic, over-the-counter market places. The data is provided by Thomson Reuters and covers all bid and ask quotes. Accordingly, we use the intraday quotes of 5- , 10- , 20- , and 30-year on-the-run JGBs to calculate bid-ask spreads in the spot markets. These bonds reflect the type of long-term maturity government bonds the Bank of Japan purchased.

We also measure liquidity in the JGB futures market by using the intraday data of the most actively traded delivery month of JGB futures, particularly the long-term (10-year) government bond futures, irrespectively the existence of 5- and 20- year bond futures. The data on JGB futures, which are traded on Osaka Exchanges, are taken from Nikkei Media Marketing. It includes all bid and ask prices, execution prices, and trading volume, which enables us to calculate liquidity measures such as various spreads and *ILLIQ*.

Although intraday data is obtained, we do not focus on the intraday effect of OMOs on liquidity because our preliminary analysis shows that the instantaneous impacts of the auction announcements at 10:10 AM are neither significant nor stable. Instead, we analyze the effect using the daily average of liquidity measures.

The bid-ask (half) spread is defined as

$$bid-ask\ spread_t = (Ask_t - bid_t)/2m_t$$

where m_t is the quote midpoint. The wider the bid-ask spread, the less liquid the government bond. We use the daily averages of the spreads taken from one-minute intervals.

The effective (half) spread is defined as

$$effective\ spread_t = q_t(p_t - m_t)/m_t$$

where q_t is an indicator variable that equals +1 for buyer-initiated trades and -1 for seller-initiated trades, p_t is the trade price, and m_t is the quote midpoint prevailing at the time of trade. We follow the standard trade-signaling approach of Lee and Ready (1991) and use the contemporaneous quotes to sign trades and calculate effective spreads. For each day, we use all JGB futures trades and quotes to calculate the average of all trades that day.

We also calculate Amihud's (2002) *ILLIQ* using the daily closing prices and daily trading volume:

$$ILLIQ_t = \frac{|r_t|}{volume_t}.$$

If the effective spreads widen when JGBs are purchased, it is of interest to decompose the spread along the lines of Glosten (1987) to determine whether the wider spread means information asymmetry between informed traders and liquidity providers, or more revenue for liquidity providers.

We estimate revenue to liquidity providers using the one-minute realized spread, which assumes the liquidity provider is able to close her position at the quote midpoint one-minute after the trade[2]. The realized spread is defined as

$$realized\ spread_t = q_t(p_t - m_{t+1})/m_t$$

where m_{t+1} is the quote midpoint one minute after the trade. In contrast, adverse selection is measured using the one minute price impact of a trade, defined using the same variables as

$$adverse\ selection_t = q_t(m_{t+1} - m_t)/m_t\ .$$

Note that there is an arithmetic identity relating the realized spread, the adverse selection, and the effective spread:

$$effective\ spread_t = realized\ spread_t + adverse\ selection_t\ .$$

In addition to asymmetric information, we use the dispersion of JGB yield forecasts among traders as a measure of information heterogeneity and the implied volatility from option prices as a measure of fundamental uncertainty. These three measures are expected to decrease if the JGB purchasing policy change mitigates market uncertainty when the Bank of Japan intervenes in the market.

The JGB yield forecasts are obtained from Quick Survey System (QSS), which conducts a monthly paper-based survey of forecasts made by professional forecasters as well as their attributes in Japanese financial markets. The number of respondents is between 130 and 150.

The implied volatility we use is the S&P/JPX VIX, which is provided by the Tokyo Stock Exchange and it measures a 30-day forecast of the variability of the long-term (10-year) JGB futures price.

Table 2 contains summary statistics and correlation coefficients for liquidity measures. There are some points worth mentioning. First, on average the adverse selection is higher than the realized spread. This is also evident from Figure 3. Both the bid-ask spreads and effective spreads fluctuated unstably for some months from April 2013, but are stabilized afterwards. The adverse selection is extremely high at the beginning of the sample period, while the realized spread takes a negative value. This suggests that the degree of information asymmetry

[2] We also analyzed using the same measures at five-minutes realized spreads and adverse selection and obtained similar results to those one-minute measures.

is very high immediately after the QQE started. Further, the correlation between the adverse selection and the realized spread is negative and close to −1.

Second, as Table 2 shows, the correlations between the Amihud's (2002) *ILLIQ* plotted as Figure 4 and the bid-ask spreads on spot and futures markets are positive and high, but the degree of correlations are higher between JGB VIX and these spreads. Especially the VIX has high correlations with the bid-ask spread and the effective spread on the futures market, whose correlation coefficients are 0.86 and 0.78, respectively.

5. Estimation Results

In this section we analyze whether permanent OMOs generally reduce market liquidity and what conditions prevent this decrease by utilizing the Bank of Japan's outright JGB purchases. We proceed in two steps. First, we test whether the change in purchasing policy by the Bank of Japan contributes to improving market liquidity. Second, we test whether the change mitigates the information asymmetry between informed traders and liquidity providers and thus enhances market liquidity.

5-1. Outright JGB Purchases and Market Liquidity

We examine how the Bank of Japan's purchasing policy had an effect on market liquidity as their policy changed. To test this, we use an event study methodology following previous literature (Andersen et al., 2003). Specifically, we set the auction day dummy (day t) and the settlement day dummy (day t+2) as explanatory variables to compare the effects of bond purchases; however, the effects may depend on the way that the Bank of Japan purchases. Hence, we suppose that the coefficients of the auction and the settlement dummies are dependent on the number of purchases in one day, the purchase amount per transaction, and the standard deviation of the purchase amounts for one day.

Furthermore, we call the day adjacent to the auction day, "following day," and include the following day dummy (day t+1) as an additional explanatory variable to see if the impact on liquidity lasts beyond a single day. We suppose that the effect of following day also depends on variables related to the purchasing policy analogously.

Therefore, our estimation regression is as follows.

$$Liquidity\ measure_t = \alpha + \beta_{1t} Auction\ day\ dummy_t + \beta_{2t} Following\ day\ dummy_t$$
$$+ \beta_{3t} Settlement\ day\ dummy_t + \sum_{i=4}^{10} \beta_i X_{it} + e_t$$

where

$$\beta_{1t} = \beta_{10} + \beta_{11} Number\ in\ a\ day_t + \beta_{12} Average\ amount + \beta_{13} S.d.of\ amount$$

$$\beta_{2t} = \beta_{20} + \beta_{21} Number\ in\ a\ day_t + \beta_{22} Average\ amount + \beta_{23} S.d.of\ amount$$
$$\beta_{3t} = \beta_{30} + \beta_{31} Number\ in\ a\ day_t + \beta_{32} Average\ amount + \beta_{33} S.d.of\ amount$$

As liquidity indicators, we use the bid-ask half spreads for current 5- , 10- , 20- , and 30-year bonds for JGB spot markets and the bid-ask spread, effective spread and *ILLIQ* for JGB futures. As control variables, we enter a Bank of Japan policy meeting day dummy, a US Federal Open Market Committee (FOMC) one-day lag dummy, and a Ministry of Finance (5-, 10-, 20-, and 30-year) tender day dummies. The lagged trading volume in the JGB futures market is also included as a control variable, although the trading volume data is not available for the JGB spot market.

Our analysis subject is confined to outright purchases of JGBs, excluding short-term purchases such as those with sell-back conditions. We also exclude purchases of treasury discount bills and the securities lending facility operation. The information on JGB auctions, such as their schedule and volume, is obtained from the website of Tokyo Tanshi Corp.

As Table 2 shows, since a number of liquidity measures are serially correlated, we use Newey-West estimators in OLS regressions to take into account autocorrelation and heteroskedasticity in the error terms in the models.

Table 3 reports the results on the bid-ask spreads for 5-, 10-, 20-, and 30-year JGBs. The estimated coefficients on the cross terms between the day dummies and the variables relating to the purchasing policy indicate that increasing the frequency of purchases, decreasing the amount, and leveling off the amounts lead to lower spreads, thus improving market liquidity both on the auction and following days. The effect of lowering the amount continues to be significant even on the settlement days. From the coefficients, it is evident that the impacts are greater for longer maturity bonds. Table 4 shows that the bid-ask spread, the effective spread, and *ILLIQ* for JGB futures are also sensitive to the change in purchasing policy. These results suggest that the way the central bank intervenes has a significant bearing on market liquidity. These effects do not die out only on the auction days but last at least three days until the operations are executed.

In order to assess whether permanent OMOs improve or reduce market liquidity, we calculate the time-varying coefficients representing the liquidity effect ($\widehat{\beta_{1t}}$, $\widehat{\beta_{2t}}$, $\widehat{\beta_{3t}}$) by exploiting the estimated coefficients obtained from the regressions and monthly averages of the number of purchases in one day, the purchase amount per transaction, and the standard deviation of the purchase amounts for one day. We rely on all estimated coefficients even though they are not significant.

Figures 5 and 6 show the time-varying $\widehat{\beta_t}$s from April 2013 to June 2014. All graphs show that the impacts are positive and high in April 2013 and gradually shift downward. Second, it is also clear that the impacts on some liquidity measures, such as the bid-ask spread and the effective spreads, become negative in the latter half sub-sample period. Taking into account the confidence interval, we find that the negative time-varying coefficients in the period are not significantly different from zero, while those in the beginning of the sample period (from April to May 2013) are significantly greater than zero[3]. Therefore, it is reasonable that the purchasing policy changes contribute to improving liquidity to the degree that the JGB purchases do not worsen the market liquidity. Lastly, the impact on liquidity is the highest on the auction days, the second highest on the following days and the lowest on the settlement days for the bid-ask spread, the effective spread, and *ILLIQ*.

5-2. The effects on asymmetric information, implied volatility, and dispersion of forecasts

We have shown that the Bank of Japan's purchasing policy change has an improved influence on market liquidity. However, what is the mechanism under which this policy change works? Following the theories by Chari (2007) and Pasquariello et al. (2014), we argue that it facilitates informed traders to forecast the time and scale of the next JGB purchases and to estimate the fundamentals, and thus, mitigates market uncertainty so that they can further engage in risk-arbitrage in the market.

To test this implication, we assess whether the following three variables are affected by the Bank of Japan's purchasing policy change: 1) the asymmetric information component of the effective spread; 2) the implied volatility obtained from option prices; and 3) the dispersion of forecasts on government bond yields. The asymmetric information and the implied volatility are obtained on a daily basis, while the forecasts are collected on a monthly basis.

Table 5 reports the results of the regressions whose dependent variables are the adverse selection, the realized spread, and the implied volatility. Leveling off the amount decreases the adverse selection and increases the realized spread on the auction and following days. On the other hand, a small amount interventions decrease the adverse selection on the settlement days. For the implied volatility, a smaller amount and leveling off the amount decrease the implied volatility on the auction, following, and settlement days.

In Figure 7, the graphs depict the time-varying coefficients of the three day dummies. The adverse selection is positive and very high in April 2013 when intervening in the market, while it becomes negative after September 2013. By contrast, the realized spread is negative but becomes positive as time goes by. Both effects are evident on the auction and following days, while the effect is not significant on the settlement days. In addition to this downward trend of time-varying coefficients of the adverse selection, the effective spread and the adverse

[3] The empirical results are not displayed in this paper but provided upon request.

selection has a high correlation (0.67), as shown at Table 2. The above evidence suggests that the adverse selection is the key component in determining the effective spread.

The effect on the JGB VIX gradually becomes negative in March 2014. The impacts of the three-day dummies are close to each other, but the magnitude is the highest on the auction days, the second highest on the following days and lowest on the settlement days.

Since the forecasts on government bond yields are collected on a monthly basis, we are not able to use the survey data in the regression analysis. However, Figure 8 shows that the standard deviations of both 1-month and 3-month forecasts decline for 5-year, 10-year, and 20-year JGB yields. These pieces of evidence suggest that the Bank of Japan's purchasing policy change has a significant contribution to mitigating market uncertainty and enhancing market liquidity.

6. Endogeneity Issues

A concern regarding the analysis presented above is the possibility that the purchases of JGBs are endogenous. If the Bank of Japan reacts to worsening liquidity positions by purchasing JGBs, then coefficient estimates will be biased. We conducted the Granger-causality using daily data and found that JGB purchases are not caused by yesterday's liquidity conditions[4]. Another possibility is that the Bank of Japan may respond to market liquidity on an intraday basis. However, this is impractical as purchases are relatively large, occur early in the morning, and would require a simultaneous response to many different liquidity indicators.

Another concern is that if the purchasing policy change enables traders to forecast the next intervention exactly, the purchasing day dummies become endogenous. In practice, however, what the Bank discloses is not the detailed schedule of purchases but rather a monthly rough schedule. Therefore, the exact timing and size of interventions remains uncertain for traders when the Bank intervenes in the market.

7. Conclusion

In this study, we investigate how the Bank of Japan's outright JGB purchases has an effect on market liquidity. Although there are the two opposing theories on the effect, their critical differences are whether OMOs have any information related to fundamentals. The large change in the Bank of Japan's purchasing policy after the monetary easing in April 2013 is a natural experiment to allow us to test the implication from the theories. The purchasing policy brought about three specific changes: 1) an increase in the frequency of purchases; 2) a decrease in the

[4] The empirical results are not displayed in this paper but provided upon request.

purchase amount per transaction; and 3) a decrease in the variability in the purchase amounts when purchased multiple times in one day. These types of policy changes eased investors' expectations on the schedule of the next purchases and their estimations of the fundamentals, reducing market uncertainty. The regression results show that these policy changes significantly contributed to the improvement of the market liquidity. In addition, the adverse selection, the implied volatility, and the dispersion of forecasts are all reduced by the policy change. These pieces of evidence suggest that central banks' communication and transparency play an important role in the large-scale government bond purchases in terms of market liquidity.

References

Amihud, Y. (2002). Illiquidity and stock returns: Cross-section and time series effects, *Journal of Financial Markets*, 5, 31–56.

Andersen, T. G., T. O. Bollerslev, F. X. Diebold, and C. Vega (2003). Micro Effects of Macro Announcements: Real-Time Price Discovery in Foreign Exchange, *American Economic Review*, 93(1), 38–62.

Andersson, M. (2010). Using intraday data to gauge financial market responses to Federal Reserve and ECB monetary policy decisions, *International Journal of Central Banking*, 6(2), 117–146.

Bernanke, S. B. (2012), Monetary Policy since the Onset of the Crisis. *Remarks at the Federal Reserve Bank of Kansas City Economic Symposium*, Jackson Hole, Wyoming, August 31, http://www.federalreserve.gov/newsevents/speech/bernanke20120831a.pdf

Bhattacharya, U. and M. Spiegel (1991). Insiders, Outsiders and Market Breakdowns, *Review of Financial Studies*, 4, 255–282.

Bhattacharya, U. and P. Weller (1997). The advantage to hiding one's hand: speculation and central bank intervention in the foreign exchange market, *Journal of Monetary Economics*, 39, 251–277.

Brunetti, C., M. Filippo, and J. H. Harris (2010). Effects of central bank intervention on the interbank market during the subprime crisis, *Review of Financial Studies*, 24(6), 2053-2083.

Chari., A. (2007). Heterogeneous market-making in foreign exchange markets: evidence from individual bank responses to central bank interventions, *Journal of Money, Credit and Banking*, 39(5), 1131–1161.

Christensen, J. H. E. and J. M. Gillan (2014). Does quantitative easing affect market liquidity?, Federal Reserve Bank of San Francisco Working Paper Series, 2013-26.

Glosten, L. R. (1987). Components of the bid ask spread and the statistical properties of transaction prices, *Journal of Finance*, 42, 1293–1307.

Harvey, R. C. and R. D. Huang (2002). The impact of the Federal Reserve Bank's open market operations, *Journal of Financial Markets*, 5, 223–257.

Inoue, H. (1999). The effects of open market operations on the price discovery process in the Japanese government securities market: an empirical study, Working Paper. https://www.bis.org/publ/cgfs11ino_c.pdf

Kandrac, J. and B. Schlusche (2014). Flow effects of large-scale asset purchases, *Economics Letters*, 121, 330–335.

Kyle, A. S. (1985). Continuous Auction and Insider Trading, *Econometrica*, 53, 1315–1385.

Lee, C. M. C., and M. J. Ready (1991). Inferring trade direction from intraday data, *Journal of Finance*, 46, 733–746.

Naranjo, A. and M. Nimalendran (2000). Government Intervention and adverse selection costs in foreign exchange markets, *Journal of Finance*, 13(2), 453–477.

Pasquariello, P., J. Roush, and C. Vega (2014). Government intervention and strategic trading in the U.S. treasury market, Working Paper, University of Michigan. http://webuser.bus.umich.edu/ppasquar/openmarket.pdf

Table 1 Changes of Purchasing Strategy of JGB

The units are the number of times, and billion yen. The data is from the website of the Tokyo Tanshi Corp.

						(times, billion yen)
Date of auctions	Average number in a day	Average days in a month	Average number in a month	Average amount per transaction	Amount in a month	Average of standard deviation of amount in a day
Jan.-March 2013	2.00	4.0	8.0	2,181	17,448	527
April	2.50	6.0	15.0	4,426	68,146	1,784
May	2.29	7.0	16.0	4,146	65,450	1,690
June	2.60	10.0	26.0	3,208	81,709	1,314
July	2.60	10.0	26.0	2,716	71,015	1,173
August	2.60	10.0	26.0	2,791	71,720	951
September	2.60	10.0	26.0	2,853	74,025	917
October	2.60	10.0	26.0	2,851	75,262	768
November	2.60	10.0	26.0	2,724	72,035	847
December	2.60	10.0	26.0	2,626	68,228	714
Jan.-June 2014	2.63	10.0	26.3	2,445	65,368	734

Table 2 Descriptive Statistics and Correlation Coefficients

This table reports summary statistics for liquidity measures and others from April 4, 2013 to June 30, 2014. Spreads are all unit-free as they are divided by the midquote. The unit of the JGB VIX is percentage (%). The JGB VIX meaures the market estimate of the price fluctuation of 10-year JGB Futures over the next 30 days.

	JGB spot				JGB futures					JGB Option
	Bid-ask spread (5 year)	Bid-ask spread (10 year)	Bid-ask spread (20 year)	Bid-ask spread (30 year)	Bid-ask spread	Effective spread	ILLIQ	Adv. selection	Realized spread	VIX
Mean	0.00030	0.00059	0.00152	0.00181	0.00004	0.00004	4.05E-08	0.00002	0.00001	3.083
Median	0.00030	0.00058	0.00152	0.00171	0.00004	0.00004	2.84E-08	0.00002	0.00001	2.680
Maximum	0.00039	0.00094	0.00207	0.00274	0.00005	0.00005	3.10E-07	0.00008	0.00002	6.550
Minimum	0.00016	0.00040	0.00087	0.00102	0.00003	0.00003	0.00E+00	0.00001	−0.00003	1.730
Std. Dev.	0.00003	0.00007	0.00021	0.00036	2.45E-06	1.65E-06	4.06E-08	5.84E-06	4.89E-06	1.154
Skewness	−0.21506	0.96051	−0.34359	0.80043	2.51802	3.74181	2.17899	3.88369	−2.92610	1.28917
Kurtosis	3.4663	6.3235	3.5283	3.1120	9.8936	24.1694	10.7157	32.6192	22.4761	3.6715
Autocorr.	0.6860	0.6040	0.7860	0.8480	0.7880	0.6490	0.1420	0.2020	0.0990	0.9520
Observations	307	307	307	307	307	307	307	307	307	307
Bid-ask (5 yr)	1.000									
Bid-ask (10 yr)	0.187	1.000								
Bid-ask (20 yr)	0.347	0.522	1.000							
Bid-ask (30 yr)	0.225	0.453	0.667	1.000						
Bid-ask (Futures)	−0.046	−0.151	−0.179	−0.172	1.000					
Effective spred (futures)	0.348	0.222	0.383	0.265	0.903	1.000				
ILLIQ (futures)	0.193	0.228	0.283	0.265	0.348	0.432	1.000			
Adv. Selection (futures)	0.204	0.124	0.274	0.203	0.520	0.669	0.308	1.000		
Realized sp. (futures)	−0.126	−0.074	−0.198	−0.153	−0.317	−0.461	−0.221	−0.968	1.000	
JGB VIX	0.427	0.312	0.488	0.400	0.856	0.777	0.392	0.378	−0.190	1.000

Table 3 The Effect of Purchasing Policy Change (JGB Spot)

This table reports the OLS slope coefficients of the following regression with the daily average of bid-ask spreads for the on-the-run JGBs:

$$Liquidity\ measure_t = \alpha + \beta_{1t} Auction\ day\ dummy_t + \beta_{2t} Following\ day\ dummy_t$$

$$+ \beta_{3t} Settlement\ day\ dummy_t + \sum_{i=4}^{10} \beta_i X_{it} + e_t$$

where

$$\beta_{1t} = \beta_{10} + \beta_{11} Number\ in\ a\ day_t + \beta_{12} Average\ amount + \beta_{13} S.d.of\ amount$$

$$\beta_{2t} = \beta_{20} + \beta_{21} Number\ in\ a\ day_t + \beta_{22} Average\ amount + \beta_{23} S.d.of\ amount$$

$$\beta_{3t} = \beta_{30} + \beta_{31} Number\ in\ a\ day_t + \beta_{32} Average\ amount + \beta_{33} S.d.of\ amount$$

The t-statistics in parentheses are calculated from Newey-West standard errors. The symbols ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively. The sample is April 4, 2013 to June 30, 2014. A constant term is not displayed.

	Bid-ask spreads of JGB spot markets							
	5 years		10 years		20 years		30 years	
Auction day dummy	1.24E-05		-1.25E-05		-2.91E-04	***	-1.81E-04	
	(0.870)		(-0.372)		(-4.442)		(-1.182)	
Auction day dummy ×	-8.18E-06	*	-1.54E-05		-4.90E-05	*	-6.49E-05	
# of auctions in a day	(-1.814)		(-1.315)		(-1.769)		(-1.303)	
Auction day dummy ×	8.18E-10		1.24E-08	*	6.67E-08	***	1.64E-07	***
average amount	(0.197)		(1.648)		(3.426)		(4.530)	
Auction day dummy ×	9.90E-09	***	1.11E-08	***	6.61E-08	***	1.28E-08	
standard deviation	(2.288)		(2.408)		(2.859)		(0.316)	
Following day dummy	2.19E-05		-1.90E-05		-3.33E-04	***	-3.19E-04	**
	(1.448)		(-0.463)		(-4.621)		(-2.216)	
Following day dummy ×	-1.59E-05	***	-5.73E-06		5.93E-05	**	-2.75E-05	
# of auctions in a day	(-3.297)		(-0.482)		(2.166)		(-0.536)	
Following day dummy ×	6.37E-09	*	6.86E-09		6.84E-08	***	1.55E-07	***
average amount	(1.851)		(0.779)		(3.333)		(3.943)	
Following day dummy ×	9.33E-09	**	7.77E-09		6.69E-08	***	3.10E-08	
standard deviation	(2.052)		(0.970)		(2.922)		(0.704)	
Settlement day dummy	-1.23E-05		-2.72E-05		-2.87E-04	***	-3.06E-04	
	(-0.846)		(-0.942)		(-3.631)		(-2.292)	
Settlement day dummy ×	-4.42E-06		-1.35E-05	*	1.72E-05		-3.71E-05	
# of auctions in a day	(-1.188)		(-1.704)		(0.649)		(-0.877)	
Settlement day dummy ×	1.00E-08	***	2.41E-08	***	9.25E-08	***	1.56E-07	***
average amount	(3.016)		(3.384)		(4.341)		(4.244)	
Settlement day dummy ×	-5.97E-10		-7.49E-09		3.26E-08		5.25E-10	
standard deviation	(-0.136)		(-0.655)		(1.334)		(0.011)	
BOJ meeting	-6.29E-07		2.25E-06		4.65E-06		4.31E-05	
	(-0.064)		(0.123)		(0.116)		(0.617)	
FOMC dummy (-1)	-1.91E-05	*	-5.75E-06		-2.16E-05		-8.89E-05	
	(-1.659)		(-0.349)		(-0.355)		(-1.154)	
Tender (5year JGB)	-5.75E-06		1.31E-05		1.39E-04	***	6.33E-05	
	(-0.702)		(0.547)		(3.381)		(0.587)	
Tender (10year JGB)	1.23E-05		1.87E-05		9.31E-05	**	1.80E-04	***
	(1.463)		(1.264)		(2.311)		(2.678)	
Tender (20year JGB)	-1.43E-05		-9.66E-06		9.17E-05		-3.41E-05	
	(-1.241)		(-0.528)		(1.496)		(-0.399)	
Tender (30year JGB)	1.48E-05		-1.75E-05		5.48E-05		1.17E-04	
	(1.861)		(-0.878)		(0.867)		(1.085)	
Observations	307		307		307		307	
Adj. R-squared	0.053		0.057		0.203		0.145	

Table 4 The Effect of Purchasing Policy Change (JGB Futures)

This table reports the OLS slope coefficients of the following regression of daily liquidity measures for JGB futures:

$$Liquidity\ measure_t = \alpha + \beta_{1t} Auction\ day\ dummy_t + \beta_{2t} Following\ day\ dummy_t$$

$$+ \beta_{3t} Settlement\ day\ dummy_t + \sum_{i=4}^{10} \beta_i X_{it} + e_t$$

where

$$\beta_{1t} = \beta_{10} + \beta_{11} Number\ in\ a\ day_t + \beta_{12} Average\ amount + \beta_{13} S.d.of\ amount$$

$$\beta_{2t} = \beta_{20} + \beta_{21} Number\ in\ a\ day_t + \beta_{22} Average\ amount + \beta_{23} S.d.of\ amount$$

$$\beta_{3t} = \beta_{30} + \beta_{31} Number\ in\ a\ day_t + \beta_{32} Average\ amount + \beta_{33} S.d.of\ amount$$

The bid-ask spreads are calculated by taking the 1 min. average of the bid-ask spreads. The effective spread is the daily average. *ILLIQ* is Amihud's (2002) illiquidity measure. The t-statistics in parentheses are calculated from Newey-West standard errors. The symbols ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively. The sample is April 4, 2013 to June 30, 2014. A constant term is not displayed.

	JGB futures market					
	Bid−ask spread		Effective spread		ILLIQ	
Auction day dummy	−3.00E−06	***	−1.77E−06	***	−6.93E−08	***
	(−3.362)		(−2.899)		(−3.277)	
Auction day dummy × # of auctions in a day	−1.86E−07		−1.80E−07		−1.34E−08	*
	(−0.560)		(−0.818)		(−1.747)	
Auction day dummy × average amount	5.60E−10	**	3.07E−10	**	7.92E−12	**
	(2.409)		(2.070)		(2.061)	
Auction day dummy × standard deviation	1.99E−09	***	1.19E−09	***	1.07E−11	**
	(5.321)		(5.267)		(1.990)	
Following day dummy	−1.83E−06	*	−5.52E−07		−1.56E−08	
	(−1.868)		(−0.920)		(−0.718)	
Following day dummy × # of auctions in a day	−3.93E−07		−3.44E−07	*	−4.05E−09	
	(−1.224)		(−1.776)		(−0.598)	
Following day dummy × average amount	5.01E−10	**	1.32E−10		6.25E−12	
	(2.067)		(0.903)		(1.254)	
Following day dummy × standard deviation	1.15E−09	***	6.90E−10	***	6.69E−12	
	(3.653)		(3.670)		(1.002)	
Settlement day dummy	−1.57E−06		−4.56E−07		−3.08E−08	*
	(−1.579)		(−0.443)		(−1.750)	
Settlement day dummy × # of auctions in a day	−4.14E−07	*	−4.12E−07		−2.61E−09	
	(−1.639)		(−1.586)		(−0.552)	
Settlement day dummy × average amount	7.74E−10	***	4.77E−10	***	1.19E−11	**
	(3.091)		(3.225)		(2.514)	
Settlement day dummy × standard deviation	3.45E−10		1.18E−11		7.72E−14	
	(1.214)		(0.038)		(0.014)	
BOJ meeting dummy	4.51E−08		−1.57E−07		−9.17E−09	
	(0.090)		(−0.438)		(−1.006)	
FOMC dummy (−1)	−3.89E−07		−2.31E−07		5.35E−09	
	(−0.658)		(−0.657)		(0.499)	
Tender (5year JGB)	−1.68E−07		−4.31E−07		1.63E−08	
	(−0.240)		(−1.474)		(1.120)	
Tender (10year JGB)	1.84E−07		−2.99E−08		−1.02E−08	
	(0.476)		(−0.087)		(−1.215)	
Tender (20year JGB)	−5.05E−07		−3.10E−07		3.00E−09	
	(−1.069)		(−0.936)		(0.320)	
Tender (30year JGB)	5.73E−07		3.20E−07		−1.56E−08	**
	(0.593)		(0.578)		(−2.057)	
Volume(−1)	6.8E−11	***	5.08E−11	***	−7.91E−14	
	(2.757)		(2.877)		(−0.207)	
Observations	306		306		306	
Adj. R−squared	0.362		0.280		0.075	

Table 5 The Effect of Purchasing Policy Change on Adverse Selection, Realized Spread, and Implied Volatility

This table reports the OLS estimates of the slope coefficients of the regression:

$$Measure_t = \alpha + \beta_{1t} Auction\ day\ dummy_t + \beta_{2t} Following\ day\ dummy_t + \beta_{3t} Settlement\ day\ dummy_t + \sum_{i=4}^{10} \beta_i X_{it} + e_t$$

where

$$\beta_{1t} = \beta_{10} + \beta_{11} Number\ in\ a\ day_t + \beta_{12} Average\ amount + \beta_{13} S.d.of\ amount$$

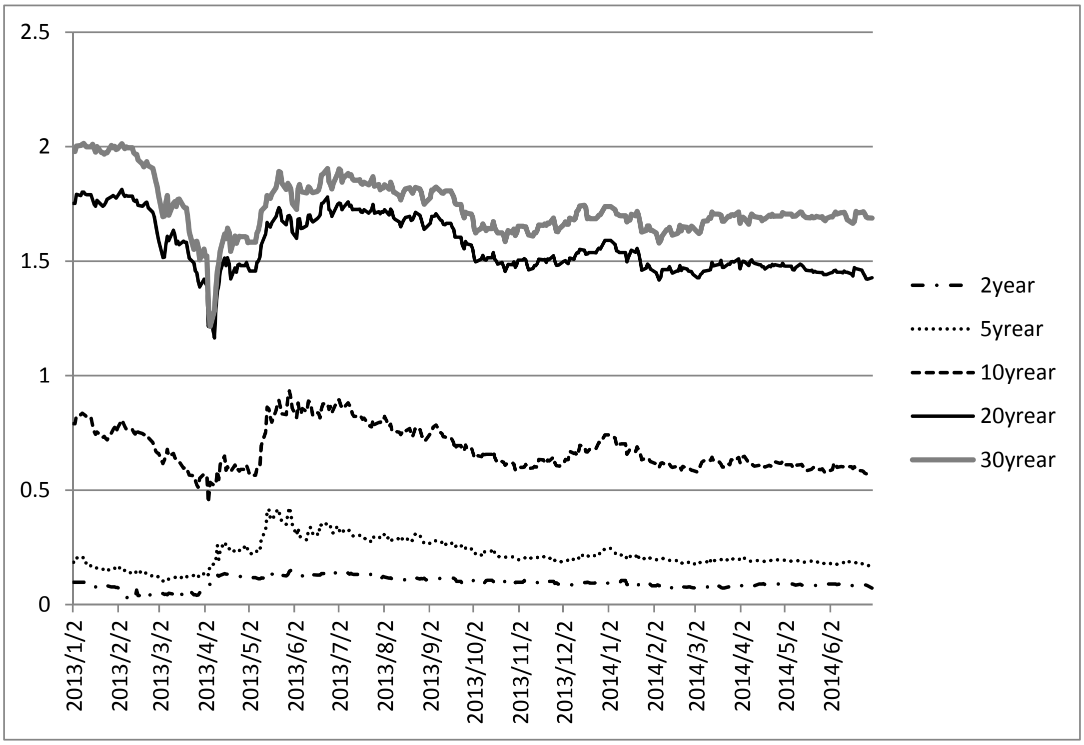
$$\beta_{2t} = \beta_{20} + \beta_{21} Number\ in\ a\ day_t + \beta_{22} Average\ amount + \beta_{23} S.d.of\ amount$$

$$\beta_{3t} = \beta_{30} + \beta_{31} Number\ in\ a\ day_t + \beta_{32} Average\ amount + \beta_{33} S.d.of\ amount$$

The adverse selection and the realized spreads are daily averages. The t-statistics in parentheses are calculated from Newey-West standard errors. The symbols ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively. The sample is April 4, 2013 to June 30, 2014. A constant term is not displayed.

	JGB futures market				JGB option market	
	Adverse selection		Realized spread		JGB VIX	
Auction day dummy	−3.79E−06		2.02E−06		−1.5796	***
	(−1.435)		(0.885)		(−3.619)	
Auction day dummy ×	−4.29E−08		−1.37E−07		−0.0236	
# of auctions in a day	(−0.047)		(−0.168)		(−0.160)	
Auction day dummy ×	5.02E−12		3.02E−10		0.0004	***
average amount	(0.011)		(0.723)		(3.374)	
Auction day dummy ×	3.47E−09	***	−2.28E−09	***	0.0006	***
standard deviation	(5.144)		(−3.873)		(3.628)	
Following day dummy	−6.26E−06	***	5.71E−06	***	−1.4288	***
	(−2.764)		(2.704)		(−3.919)	
Following day dummy ×	8.09E−07		−1.15E−06	*	−0.1341	
# of auctions in a day	(1.119)		(−1.719)		(−0.909)	
Following day dummy ×	3.12E−10		−1.80E−10		0.0004	***
average amount	(0.682)		(−0.421)		(3.773)	
Following day dummy ×	2.19E−09	***	−1.50E−09	***	0.0006	***
standard deviation	(3.463)		(−2.694)		(4.493)	
Settlement day dummy	9.03E−07		−1.36E−06		−1.4826	***
	(0.211)		(−0.384)		(−3.307)	
Settlement day dummy ×	−1.46E−06		1.04E−06		−0.1718	
# of auctions in a day	(−1.257)		(1.083)		(−1.479)	
Settlement day dummy ×	1.71E−09	***	−1.23E−09	**	0.0005	***
average amount	(2.708)		(−2.197)		(4.918)	
Settlement day dummy ×	−2.03E−09		2.04E−09	**	0.0004	***
standard deviation	(−1.617)		(1.992)		(2.879)	
BOJ meeting	−5.30E−07		3.73E−07		−0.0155	
	(−0.388)		(0.298)		(−0.061)	
FOMC dummy (−1)	−1.56E−06		1.33E−06		−0.3164	
	(−1.150)		(0.938)		(−1.536)	
Tender (5year JGB)	−2.73E−07		−1.58E−07		−0.2282	
	(−0.202)		(−0.128)		(−0.808)	
Tender (10year JGB)	−3.60E−07		3.30E−07		0.2901	
	(−0.252)		(0.271)		(1.218)	
Tender (20year JGB)	−1.44E−06		1.13E−06		−0.0414	
	(−1.257)		(1.174)		(−0.139)	
Tender (30year JGB)	−8.17E−07		1.14E−06		−0.0004	
	(−0.699)		(1.304)		(−0.001)	
Volume(−1)	1.07E−10	***	−5.64E−11		0.00002	*
	(2.050)		(−1.189)		(1.895)	
Observations	306		306		306	
Adj. R−squared	0.119		0.054		0.423	

Figure 1 JGB Yields



(Data) Bloomberg

Figure 2 Implied Volatility

The Tokyo Stock Exchange (JPX) provides the model-free implied volatility obtained from option prices.

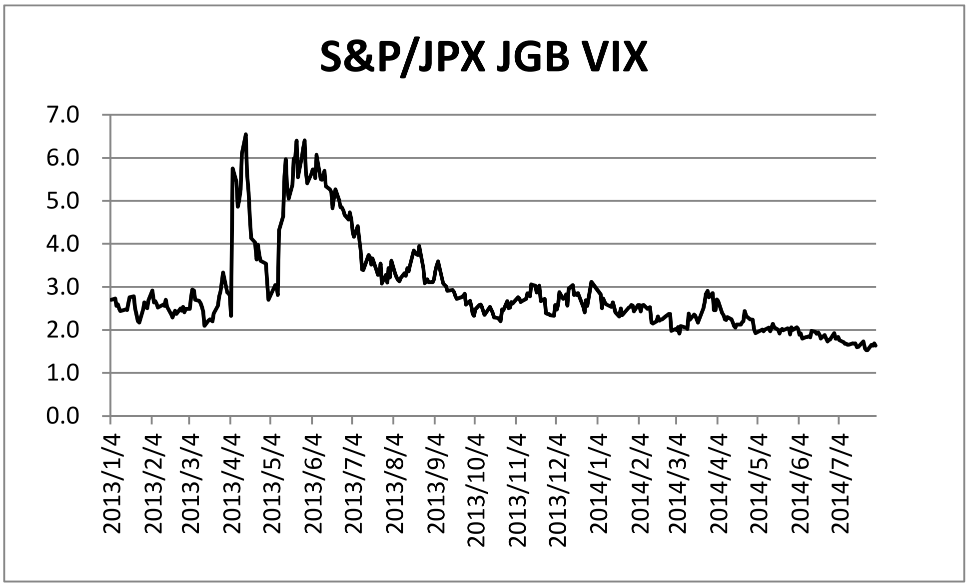
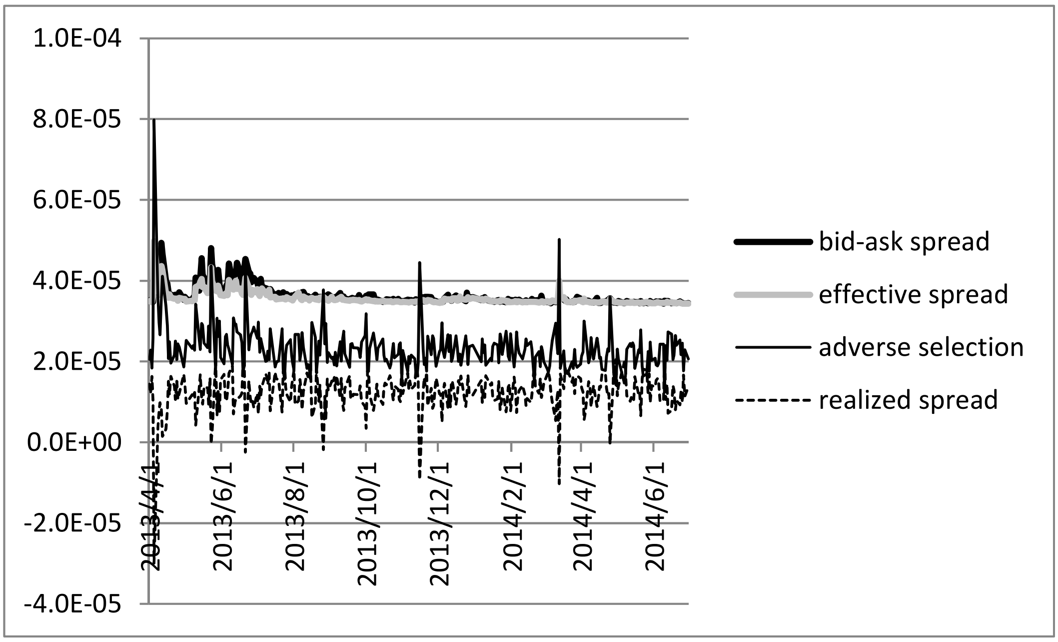
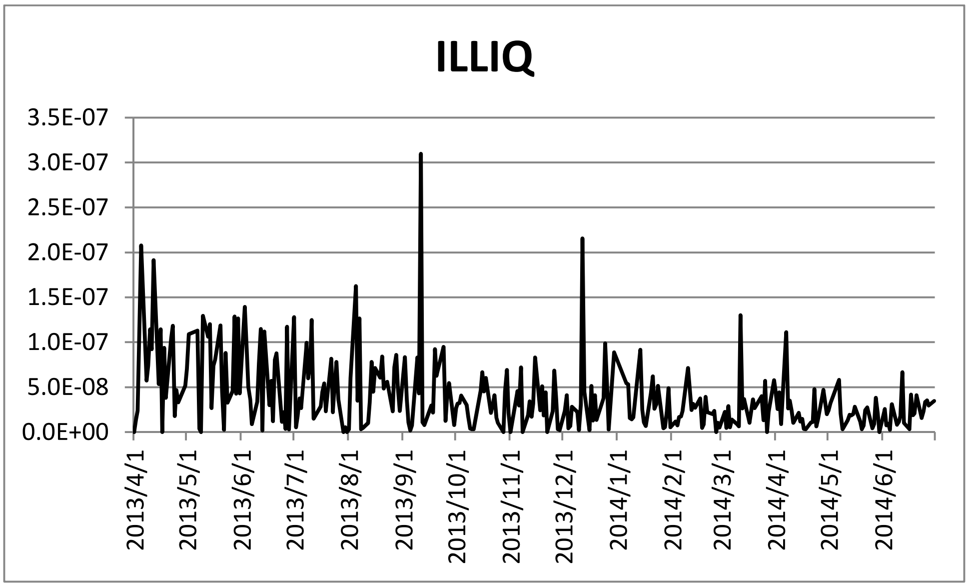


Figure 3 Comparison of Spreads and Spread Components



(Data) The JGB futures price and volume data are from Nikkei Media Marketing

Figure 4 Amihud's (2002) Illiquidity Measure, *ILLIQ*



(Data) The JGB futures price and volume data are from Nikkei Media Marketing

Figure 5 Liquidity Impacts of Interventions in the JGB Spot Market

(5-, 10-, 20-, 30-Year JGBs)

$$Liquidity\ measure_t = \alpha + \beta_{1t} Auction\ day\ dummy_t + \beta_{2t} Following\ day\ dummy_t$$

$$+ \beta_{3t} Settlement\ day\ dummy_t + \sum_{i=4}^{10} \beta_i X_{it} + e_t$$

where

$$\beta_{1t} = \beta_{10} + \beta_{11} Number\ in\ a\ day_t + \beta_{12} Average\ amount + \beta_{13} S.d.of\ amount$$

$$\beta_{2t} = \beta_{20} + \beta_{21} Number\ in\ a\ day_t + \beta_{22} Average\ amount + \beta_{23} S.d.of\ amount$$

$$\beta_{3t} = \beta_{30} + \beta_{31} Number\ in\ a\ day_t + \beta_{32} Average\ amount + \beta_{33} S.d.of\ amount$$

These graphs show the time-varying coefficient of the auction day dummy ($\widehat{\beta_{1t}}$), that of the following day dummy ($\widehat{\beta_{2t}}$), and that of the settlement day dummy ($\widehat{\beta_{3t}}$). These coefficients are calculated with the regression estimates and the monthly averages of the number of purchases in a day, the monthly averages of the purchasing amount and the monthly average of the standard deviation of the daily amounts.

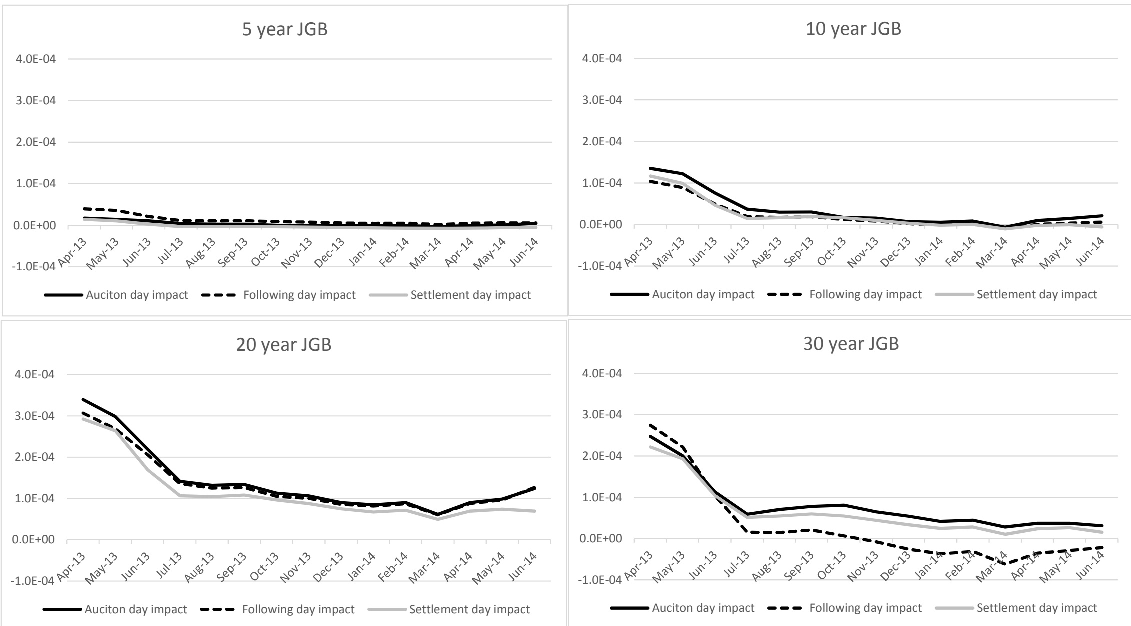


Figure 6 Liquidity Impacts of Interventions in the JGB Futures Market

(Bid-ask Spread, Effective Spreads, *ILLIQ*)

$$Liquidity\ measure_t = \alpha + \beta_{1t} Auction\ day\ dummy_t + \beta_{2t} Following\ day\ dummy_t$$

$$+ \beta_{3t} Settlement\ day\ dummy_t + \sum_{i=4}^{10} \beta_i X_{it} + e_t$$

where

$$\beta_{1t} = \beta_{10} + \beta_{11} Number\ in\ a\ day_t + \beta_{12} Average\ amount + \beta_{13} S.d.of\ amount$$

$$\beta_{2t} = \beta_{20} + \beta_{21} Number\ in\ a\ day_t + \beta_{22} Average\ amount + \beta_{23} S.d.of\ amount$$

$$\beta_{3t} = \beta_{30} + \beta_{31} Number\ in\ a\ day_t + \beta_{32} Average\ amount + \beta_{33} S.d.of\ amount$$

These graphs show the time-varying coefficient of the auction day dummy ($\widehat{\beta_{1t}}$), that of the following day dummy ($\widehat{\beta_{2t}}$), and that of the settlement day dummy ($\widehat{\beta_{3t}}$). These coefficients are calculated with the regression estimates and the monthly averages of the number of purchases in a day, the monthly averages of the purchasing amount and the monthly average of the standard deviation of the daily amounts.

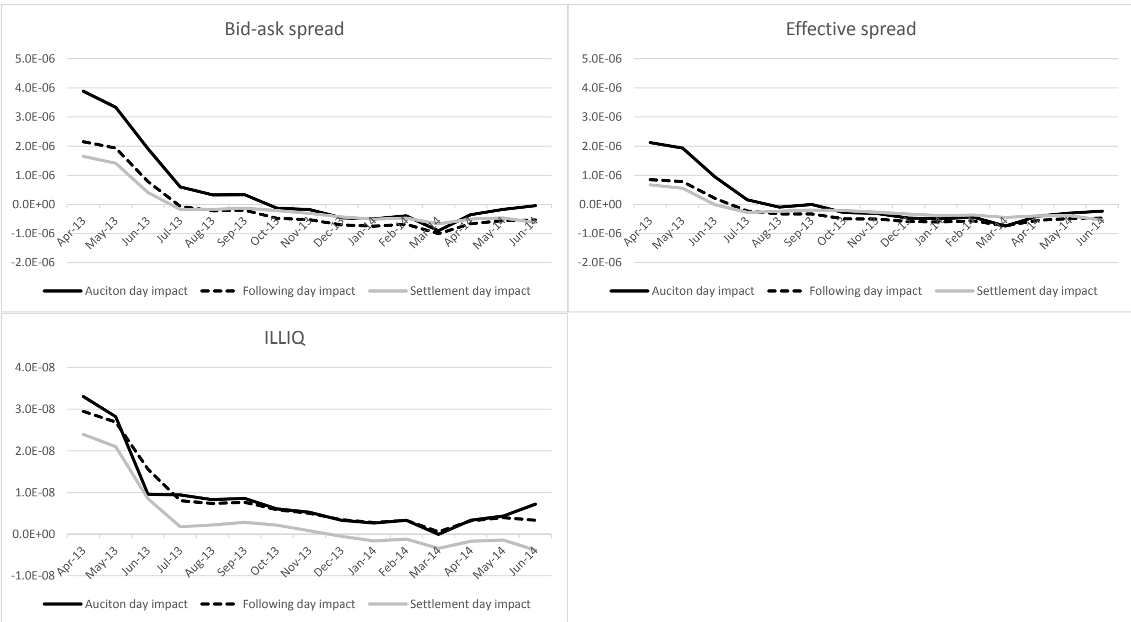


Figure 7 Impacts of Interventions in the Futures and Option Markets

(Adverse Selection, Realized Spreads, JGB VIX)

$$Liquidity\ measure_t = \alpha + \beta_{1t} Auction\ day\ dummy_t + \beta_{2t} Following\ day\ dummy_t + \beta_{3t} Settlement\ day\ dummy_t + \sum_{i=4}^{10} \beta_i X_{it} + e_t$$

where

$$\beta_{1t} = \beta_{10} + \beta_{11} Number\ in\ a\ day_t + \beta_{12} Average\ amount + \beta_{13} S.d.\ of\ amount$$

$$\beta_{2t} = \beta_{20} + \beta_{21} Number\ in\ a\ day_t + \beta_{22} Average\ amount + \beta_{23} S.d.\ of\ amount$$

$$\beta_{3t} = \beta_{30} + \beta_{31} Number\ in\ a\ day_t + \beta_{32} Average\ amount + \beta_{33} S.d.\ of\ amount$$

These graphs show the time-varying coefficient of the auction day dummy ($\widehat{\beta_{1t}}$), that of the following day dummy ($\widehat{\beta_{2t}}$), and that of the settlement day dummy ($\widehat{\beta_{3t}}$). These coefficients are calculated with the regression estimates and the monthly averages of the number of purchases in a day, the monthly averages of the purchasing amount and the monthly average of the standard deviation of the daily amounts.

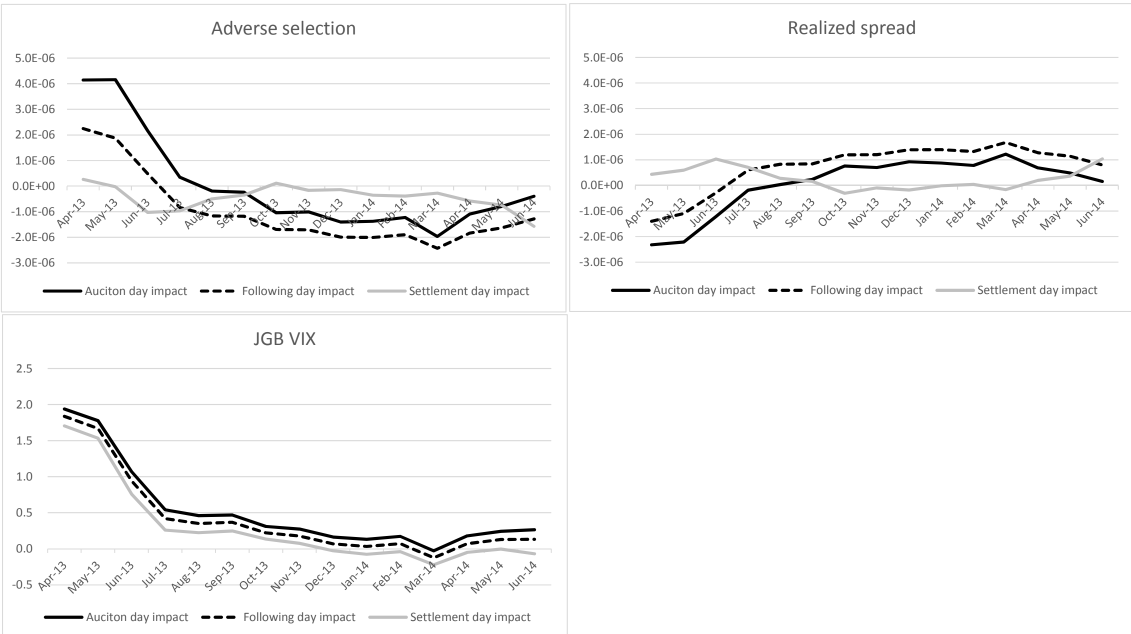


Figure 8 Dispersion of JGB Yield Forecasts among Traders

The below graphs depict the standard deviations of one-month and three-month forecasts for 5-, 10-, and 20-year JGB yields. The Quick Survey System (QSS) conducts a monthly paper-based survey of forecasts made by professional forecasters as well as their attributes in Japanese financial markets. The number of respondents is between 130 and 150.