Quantitative Easing and Liquidity in the Japanese Government Bond Market

Iwatsubo, Kentaro

Taichi, Tomoki

(Citation)
International Review of Finance,18(3):463-475

(Issue Date)
2018-09

(Resource Type)
journal article

(Version)
Accepted Manuscript

Quantitative Easing and Liquidity in the Japanese Government Bond Market

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 such a 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 auction; 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

The authors are grateful to Editor Prof. Ramazan Gencay, an anonymous referee, Takashi Hatakeda, Bernd Hayo, Kazuhito Ikeo, Kazuhiko Ohashi, Wataru Ohta, Paolo Pasquariello, Jie Qin, Ghon Rhee, Toshio Serita, Hideki Takada, Toyoharu Takahashi, Hitoshi Takehara, Yasuhiko Tanigawa, Kazuo Ueda, Toshiaki Watanabe, and Toshinao Yoshiba, as well as the seminar participants at the Bank of Japan Finance Workshop. This work was supported by JSPS KAKENHI Grant Number 16K03742.

Ⅰ. Introduction

In April 2013, newly inaugurated Bank of Japan Governor Kuroda accelerated the bank's quantitative easing program and initiated the purchase of long-term government bonds. This was called the "Quantitative and Qualitative Monetary Easing (QQE)". Although the Japanese financial market responded strongly to this policy, the government bond market recorded historically violent fluctuations. For example, rates on mid-term Japanese government bonds (JGBs) such as two-year and five-year bonds rose before slowly decreasing over time, while rates on long-term (10-year) and super long-term (20-year) JGBs briefly fell then rose again. Surprisingly, 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 addition, the implied volatility calculated from the option prices of JGBs rose significantly. These 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 three times more in May.

The possible side effects of large-scale government bond purchasing have been addressed by many academicians 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 those of large government bond holders such as life and non-life insurance firms because of its rapid purchasing behavior, resulting in a skewed bond distribution with a focus on 5- , 10- , 20- , and 30-year newly issued bonds. Accordingly, market participants have become worried about the possible lack of floating government bonds in the market.

In general, does the outright purchase of government bonds by financial authorities deteriorate market liquidity? Do conditions exist that can prevent such a decrease? During and after phase two of the QQE policy announced in October 2014, no confusion was evident, nor was any anxiety about liquidity apparent during phase one of monetary easing in April 2013. 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 Europe are split into two views: the theory that such 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). No consensus has thus far 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 monetary easing in April 2013 has shown an improved influence on market liquidity in the

government bond market, as evidenced by the decrease in quote spreads and Amihud's (2002) *ILLIQ*. In particular, the purchasing policy has brought about three specific changes: 1) an increase in the frequency of purchases; 2) a decrease in the purchase amount per auction; and 3) a decrease in the variability in the purchase amounts when purchased multiple times in a day. We argue that these types of policy changes have eased investors' forecasts on the purchasing schedule and helped reduce market uncertainty. We also 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, however, this impact gradually decreases as the purchasing policy changes. Model-free implied volatility also shows a similar pattern. Together with the downward trend in the dispersion of JGB yield forecasts among market participants, these pieces of evidence support the theory that central banks' communication and transparency play a significant role in 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 endogeneity issues and Section 7 concludes the paper.

Ⅱ. Literature Review and Hypotheses

Although numerous studies have examined how open market operations (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 (2002), one of the earliest studies of the subject, use intraday data on government bond prices from 1982 to 1988 to 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 monetary policy decisions by the Federal Reserve Board (FRB), while Inoue (1999) discovers that Japan's OMOs increased the trade volume in the government bond market and the volatility of government bond prices.

By using data covering 2001 to 2007, however, 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 policy worsens market liquidity. In that study, Pasquariello et al. (2014) focus on the fact that FRB Chairman Alan Greenspan has made the US Federal Open Market Committee (FOMC) increasingly transparent by announcing monetary policy intentions and disclosing the federal funds target rate to the public. This change has made OMOs virtually uninformative about the Federal Reserve's future monetary policy stance.

Among the recent growing literature on large-scale asset purchase programs, Kandrac and

Schlusche (2013) find no significant liquidity effects associated with Treasury purchases. By contrast, Christensen and Gillan (2014) analyze the effect of the Treasury inflation-protected securities (TIPS) purchases included in the FRB's Q2 program on the functioning of the market for TIPS and related market for inflation swaps, finding that the liquidity premium reduced because of 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 in studies of central bank intervention in foreign exchange markets (see Bhattacharya and Weller, 1997; Naranjo and Nimalendran, 2000).

By adopting a microstructure model with strategic informed traders, Chari (2007) assumes that central banks are an informed insider 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 make 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 contrary, rational speculators (i.e., strategic informed traders) in the government bond market also have private information about the central bank's objectives.

Furthermore, the following two conditions are set so that information may differ across market participants 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 about future prices increases and market liquidity worsens. In particular, this uncertainty is intensified when central bank interventions are unexpected. In such a case, bid–ask spreads increase because of adverse selection risk and price volatility rises.

Conversely, the theoretical model developed by Pasquariello et al. (2014) shows that OMOs improve market liquidity and that the magnitude of this impact depends on the market's informational environment. The critical assumption of this theory is that although central banks are an informed trader facing a trade-off between policy motives (a non-public and uninformed price target) and the expected cost of its intervention, there is no information related to the fundamentals in OMOs, since they release their monetary policy decisions and policy details to the market before conducting OMOs. Therefore, the 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 the assumptions made by the two competing theories is whether OMOs have any information on the fundamentals. The Japanese experience allows us to test these theories since the Bank of Japan changed its JGB purchasing policy to enable traders to forecast the timing and scale of OMOs and estimate the fundamentals easily following the reduced market liquidity experienced during monetary easing. The Bank of Japan made its interventions more transparent by pre-announcing the rough monthly schedule of purchases, increasing the frequency of trades and decreasing the purchase amount per auction. Therefore, we expect that government bond purchases do not worsen, or may even improve, market liquidity after the Bank of Japan has changed its policy, as the theory of Pasquariello et al. (2014) predicts.

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

With the aim of overcoming the 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 started to double the monetary base and amounts outstanding of JGBs as well as exchange-traded funds in two years, and more than doubled the average remaining maturity of JGB purchases. The Bank of Japan also purchased JGBs from financial institutions in the secondary market, increasing its amount outstanding 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, these 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 purchases of government bonds. It increased the frequency of its purchases and lowered the purchase amount per auction. Another apparent characteristic is that the variability in the purchasing amount decreased then leveled off in cases where there were multiple purchases on one day. Furthermore, the Bank of Japan began to announce its monthly purchasing rate ex ante. Specifically, although the detailed schedule and the exact amount of the Bank of Japan's auctions were not disclosed in advance, a broad pattern was shared with market participants.

The following is an example of the actual business procedures of OMOs. At 10:10 in the morning, the Bank of Japan offers outright purchases of JGBs 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

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

Bank of Japan's website and others. The purchases are then executed generally two business days after the auction day.

Ⅳ. Data

Although intraday data on the prices of the JGB futures traded on stock exchanges are available in Japan, intraday price data on over-the-counter (OTC) trading of active JGBs (spot) are scarce. Among the various OTC brokers dealing with JGBs, the biggest broker, Japan Bond Trading Co., Ltd., discloses only execution prices and yields, which makes it impossible to measure liquidity. As alternative broker's data, we use intraday data from Tradeweb, one of the top JGB brokers operating electronic OTC marketplaces. The data are provided by Thomson Reuters and they cover all bid and ask quotes. Accordingly, we use the intraday quotes of 5-, 10-, 20-, and 30-year on-the-run JGBs to calculate the bid‐ask spreads in the spot markets. These bonds reflect the type of long-term maturity government bonds purchased by the Bank of Japan.

We also measure liquidity in the JGB futures market by using intraday data on the most actively traded delivery month of JGB futures, particularly long-term (10-year) government bond futures, irrespective of 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. They include all bid and ask prices, execution prices, and trading volume, which enables us to calculate liquidity measures such as various spreads and *ILLIQ*. However, although intraday data are 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 by using the daily average of the liquidity measures.

We measure liquidity by using bid–ask half-spreads, effective half-spreads, one-minute realized spreads, one-minute adverse selection (price impacts), and Amihud's (2002) *ILLIQ*. All of the spreads are measured as simple average and expressed as a proportion of the prevailing midpoint. The effective spread is the difference between the midpoint of the bid and ask quotes and the actual transaction price. The realized spread measures revenue to liquidity providers because we assume that the liquidity provider is able to close its position at the quote midpoint one minute after the trade. By contrast, the adverse selection measures gross losses to liquidity providers using the one minute change in quote midpoint. We also calculate Amihud's (2002) *ILLIQ* by using daily closing prices and daily trading volume.

In addition to the adverse selection as a measure of information asymmetry, we use the dispersion of JGB yield forecasts among traders to measure information heterogeneity and use the implied volatility from the option prices to measure 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 the Quick Survey

System, 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 about 130–150. The implied volatility we use is the S&P/JPX VIX provided by the Tokyo Stock Exchange, which measures a 30-day-ahead forecast of the variability of the long-term (10-year) JGB futures price.

Ⅴ. Estimation Results

A. Outright JGB Purchases and Market Liquidity

We examine how the Bank of Japan's purchasing policy affected market liquidity as its policy was changing. To test this, we use an event study methodology. We call the day on which the target bond for outright purchasing and purchase amount are announced the "auction day", and the day on which the government bond purchase is executed the "settlement day". We set the auction day dummy (day t) and settlement day dummy (day t+2) as explanatory variables to compare the effects of bond purchases, while the effects may depend on the way in which the Bank of Japan makes its purchases. Hence, we suppose that the coefficients of the auction and settlement day dummies are dependent on the number of auctions each day, average purchase amount per auction, and standard deviation of the purchase amounts for each day.

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

Suppose there are two auctions for difference maturities at day t. One is 200 billion yen and the other is 120 billion yen. In this case, the number of auctions, average purchase amount per auction, and the standard deviation of the purchase amounts are two times, 160 billion yen, and 40 billion yen, respectively. These variables take the values if the corresponding day dummies (auction/following/settlement) take 1, while they take zero when the day dummies take zero. Therefore, our estimation regression is as follows.

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

where

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

$$\beta_{2t} = \beta_{20} + \beta_{21} Number\ \ in\ \ a\ \ day_{t-1} + \beta_{22} Average\ \ amount_{t-1}$$

$$+\beta_{23} S.d.of \quad amount_{t-1}$$

$$\beta_{3t} = \beta_{30} + \beta_{31} Number \quad in \quad a \quad day_{t-2} + \beta_{32} Average \quad amount_{t-2}$$

$$+\beta_{33} S.d.of \quad amount_{t-2}$$

As liquidity indicators, we use the bid-ask half spreads for current 5-, 10-, 20-, and 30-year bonds for the 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 FOMC one-day lag dummy, and Ministry of Finance (5-, 10-, 20-, and 30-year) tender day dummies. The one-day lagged trading volume in the JGB futures market is also included as a control variable, although the trading volume data is unavailable 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. Information on JGB auctions such as their schedule and volume is obtained from the website of Tokyo Tanshi Corp.

Since a number of liquidity measures are serially correlated, we use Newey-West estimators in OLS regressions to take into account autocorrelation and heteroscedasticity in the error terms in the models. The estimation period is from April 2013 to June 2014.

The regression results of the bid-ask spreads for 5-, 10-, 20-, and 30-year JGBs 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 auction and following days.[2] Moreover, the effect of lowering the amount continues to be significant even on settlement days. Furthermore, from the coefficients, it is evident that the impacts are greater for longer maturity bonds.

They also show that the bid-ask spread, effective spread, and *ILLIQ* for JGB futures are also sensitive to the change in purchasing policy. These results suggest that the way in which the central bank intervenes has a significant bearing on market liquidity. These effects do not die out only on auction days but rather last at least three days until the operations are executed.

To assess whether permanent OMOs improve or reduce market liquidity, we next 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 auctions each day, average purchase amount per auction, and standard deviation of the purchase amounts for each day. We rely on all the estimated coefficients even though they are not significant.

Figures 1 graphs the time-varying $\widehat{\beta_t}$s from April 2013 to June 2014, showing that the impacts are positive and high in April 2013 and gradually shift downward. Second, the impacts on some liquidity measures such as the bid–ask spread and effective spread become negative in the latter half of the

[2] The empirical results are displayed in
https://www.imes.boj.or.jp/research/papers/english/16-E-12.pdf

sample period. Taking the confidence interval into account, we find that the negative time-varying coefficients in the period are not significantly different from zero, while those at the beginning of the sample period (especially from April to May 2013) are significantly greater than zero. Therefore, the purchasing policy change contributes to improving liquidity to the degree that JGB purchases do not worsen market liquidity. Lastly, the impact on liquidity is the highest on auction days, second highest on following days, and lowest on settlement days for the bid–ask spread, the effective spread, and *ILLIQ*.

B. Effects on asymmetric information, implied volatility, and dispersion of forecasts

We have shown that the Bank of Japan's purchasing policy change had an improved influence on market liquidity. However, under which mechanism does this policy change work? Following the theories proposed by Chari (2007) and Pasquariello et al. (2014), we argue that it facilitates informed traders to forecast the time and scale of future JGB purchases and estimate the fundamentals, thus mitigating market uncertainty and allowing such traders to engage more 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 implied volatility are obtained on a daily basis, while forecasts are collected on a monthly basis.

The results of the regressions whose dependent variables are the adverse selection, realized spread, and implied volatility show that leveling off the amount decreases the adverse selection, while it increases the realized spread on auction and on following days.[3] By contrast, small amount interventions decrease the adverse selection on settlement days. For implied volatility, a smaller amount and leveling off the amount decrease implied volatility on auction days, following days, and settlement days.

Figure 2 depicts the time-varying coefficients of the three day dummies. The impact on the adverse selection is positive and very high in April 2013 at the point of market intervention, while it becomes negative after August 2013. By contrast, that on the realized spread is negative but becomes positive over time. Looking at the confidence interval, we find that the coefficients of the adverse selection and the realized spread are significant only at the beginning of the sample period (April and May 2013). This shows that the informational asymmetry widens at the time of reduced liquidity and it benefits the informed traders and hurts the liquidity providers. However, the informational gap becomes less significant as the BOJ purchasing policy changes.

[3] The empirical results are displayed in
https://www.imes.boj.or.jp/research/papers/english/16-E-12.pdf

In addition to this downward trend of the time-varying coefficients of the adverse selection, the effective spread and the adverse selection have a high correlation (0.67).[4] The above evidence suggests that the adverse selection is the key component to determining the effective spread.

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

Since forecasts of government bond yields are collected on a monthly basis, we are unable to use the survey data in the regression analysis. However, the standard deviations of both the one-month- and the three-month-ahead forecasts among traders decline for 5-year, 10-year, and 20-year JGB yields during the sample period.[5] These pieces of evidence suggest that the Bank of Japan's purchasing policy change made a significant contribution to mitigating market uncertainty and enhancing market liquidity.

Ⅵ. 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 the coefficient estimates will be biased. We thus conducted a Granger-causality test by using daily data and found that JGB purchases are not caused by yesterday's liquidity conditions.[6] 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, the bank only discloses a rough monthly schedule. Therefore, the exact timing and size of interventions remain uncertain for traders when the bank intervenes in the market.

Ⅶ. Conclusion

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

[4] The summary statistics are displayed in
https://www.imes.boj.or.jp/research/papers/english/16-E-12.pdf
[5] The empirical results are displayed in
https://www.imes.boj.or.jp/research/papers/english/16-E-12.pdf
[6] The empirical results are not displayed in this paper but can be provided upon request.

an increase in the frequency of auctions; 2) a decrease in the purchase amount per auction; and 3) a decrease in the variability in the purchase amounts when purchased multiple times on one day. These types of policy changes eased investors' expectations on the schedule of future purchases and their estimations of the fundamentals, thereby reducing market uncertainty. The regression results show that these policy changes significantly contributed to improving the market liquidity. In addition, the adverse selection, implied volatility, and dispersion of forecasts are all reduced following the policy change. These pieces of evidence suggest that central banks' communication and transparency play an important role in 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.

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.

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

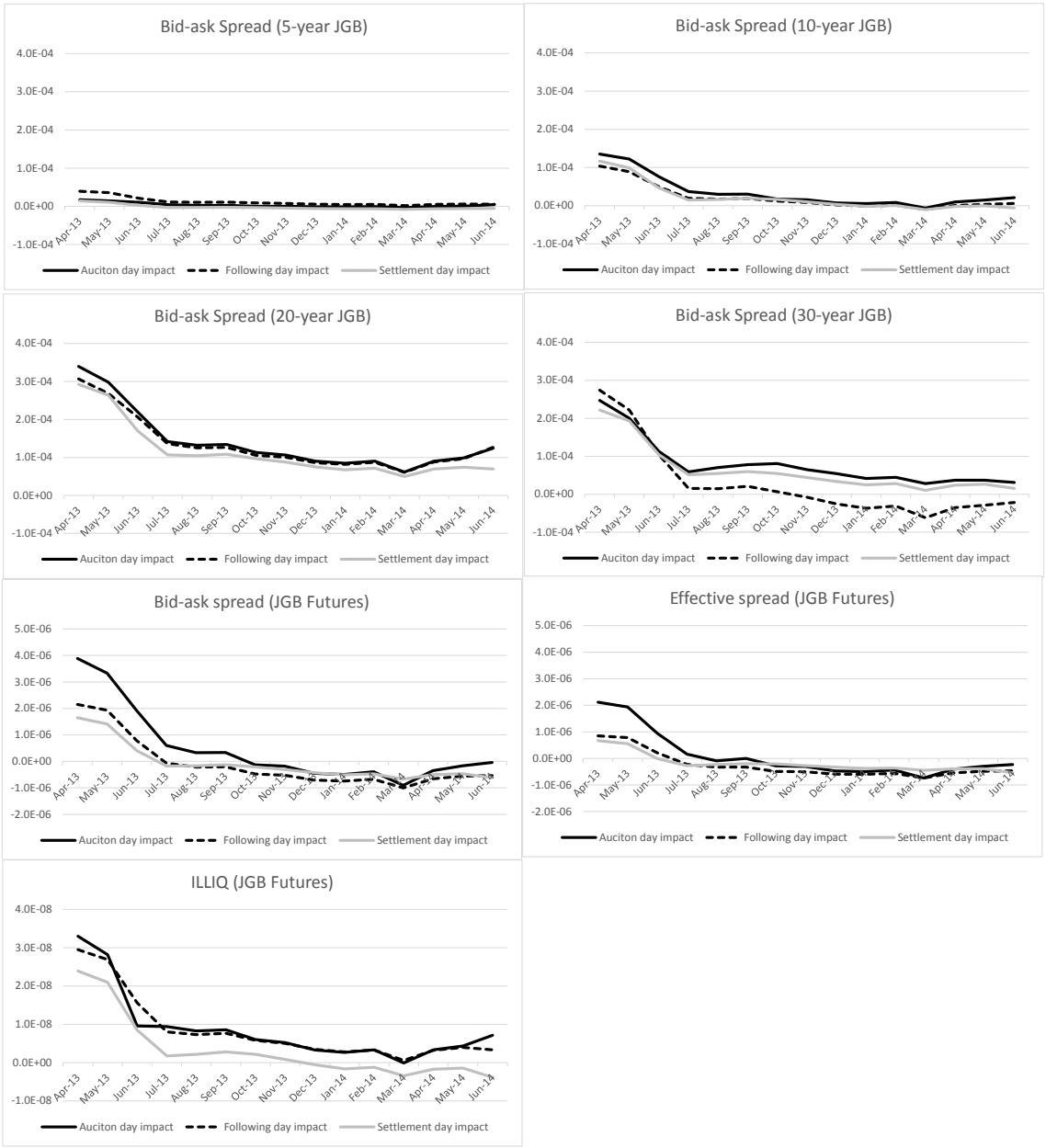
Kandrac, J. and B. Schlusche (2013). 'Flow effects of large-scale asset purchases', *Economics Letters*, 121, 330–335.

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

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

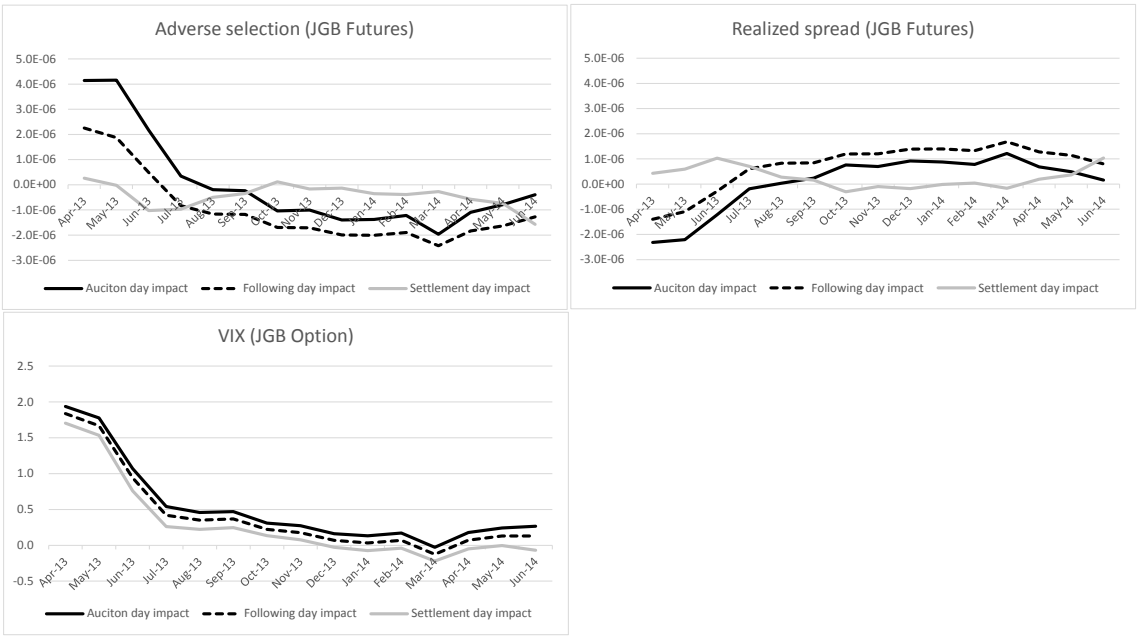
Pasquariello, P., J. Roush, and C. Vega (2014). 'Government intervention and strategic trading in the U.S. treasury market', Working Paper, University of Michigan. http://webuser.bus.umich.edu/ppasquar/openmarket.pdf

Figure 1 Liquidity Impacts of Interventions in the JGB Spot and Futures Markets



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 ($\widehat{\beta_{3t}}$).

Figure 2 Impacts of Interventions in the Futures and Option Markets



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 ($\widehat{\beta_{3t}}$).