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Japanese Repo and Call Markets Before, During, and Emerging from the Financial Crisis

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Abstract

We empirically investigate the relationship between the Japanese general collateral (GC) repurchase agreement (repo) and uncollateralized call rates before, during, and emerging from the recent financial crisis. Unlike the US and many other countries, the Japanese GC repo rate has been higher than the uncollateralized call rate, despite the former being secured by collateral. Moreover, during the financial crisis, the Japanese GC repo rate rose, whereas the US Treasury GC repo rate decreased. The results of our empirical analysis suggest that segmentation between the Japanese repo and call markets is a key factor explaining these features. The analysis also reveals how much changes in the policy target rate and the current account balances at the Bank of Japan, institutional changes in the payment system, and various policy and market events affected both the repo and call rates.

Keywords: repurchase agreement (repo); call markets; monetary policy implementation; financial crisis; market segmentation; vector error correction model; threshold ARCH

JEL classification: E43, E52, E58, G01, G12

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1 Introduction

The first step in the monetary policy transmission process in normal times is the link across short-term funding markets, whereby a change in the target policy rate, such as the federal funds rate in the US, is immediately propagated to other short-term interest rates. However, during the recent financial crisis starting in 2007, short-term funding markets, including repurchase agreement (repo) markets, became strained in many developed countries because of heightened concerns about counterparty credit risk and greater uncertainty about the value of collateral, and as a result, the links between the policy and repo rates weakened considerably. Furthermore, after policy rates were cut to near-zero levels in many developed countries and no longer acted as the main tool of monetary policy, the links with repo rates ceased to serve as part of the monetary policy transmission process.

The purpose of this paper is to investigate empirically the relationship between the repo rate and the policy rate, that is, the uncollateralized overnight call rate, in Japan. Although the Bank of Japan has adopted a zero-interest-rate policy since the late 1990s, which corresponded to an early stage of development in Japan's repo markets, the repo and call rates appeared to be still closely linked when the interest rate policy were intermittently normalized, especially between mid-2006 and late 2008. Besides that, we observe some unique features in the relationship between repo and call rates in Japan. Unlike the US and many other countries, the Japanese general collateral (GC) repo rate has been higher than the uncollateralized call rate, despite the former being secured by collateral. Moreover, during the financial crisis, the Japanese GC repo rate rose, whereas the US Treasury GC repo rate decreased because of a "flight to quality." We first attempt to explain these features by reviewing the basic facts on the Japanese repo and call markets

and comparing them with those in the US and other developed countries. We then quantitatively examine the relationship between the Japanese GC repo and call rates by conducting a formal empirical analysis following Bech, Klee, and Stebunovs (2012), who examined the relationship between the US Treasury GC repo and federal funds rates before, during, and emerging from the financial crisis using a vector error correction model.

Our results suggest that segmentation between the Japanese repo and call markets was one of the key factors explaining the above features in the relationship between the two rates. In particular, during the financial crisis, the larger presence of foreign financial institutions in the repo market relative to the call market led to a rise in the repo rate, rather than a decrease, in response to a distress in foreign currency short-term funding markets. Our results are also consistent with the fact that Japanese major banks became reluctant to undertake arbitrage transactions between the two markets during the financial crisis. Moreover, our empirical analysis reveals how much changes in the policy target rate and the current account balances at the Bank of Japan, institutional changes in the payment system, and various policy and market events affected both the repo and call rates before, during, and emerging from the financial crisis.

Since the outbreak of the financial crisis, many studies have investigated the relationship among short-term funding markets and the effects of monetary policy on these markets in both the US and Europe. Other than Bech, Klee, and Stebunovs (2012), Marquez, Morse, and Schlusche (2012) examined the interplay between the US Federal Reserve's balance sheet and overnight interest rates, while Mancini, Ranaldo, and Wrampelmeyer (2014) conducted empirical analysis of the euro interbank repo market. However, there are far fewer analyses of Japanese short-term funding markets, partly because mar-

ket trading and functioning have long been paralyzed, at least to some extent, by the zero-interest-rate policy since the late 1990s. Regarding the call market, Hayashi (2001) and Uesugi (2002) examined the relationship between the call rate and reserve balances. This so-called "liquidity effect" is also examined in our empirical analysis. As for the repo market, Baba and Inamura (2004) examined the pricing mechanism of the Japanese repo market, focusing on the linkage between the repo and government bond markets. To the best of our knowledge, however, no previous study has conducted an empirical analysis focusing on the relationship between the Japanese repo and call rates.[1]

The remainder of the paper is organized as follows. In Section 2, we review the basic facts on the Japanese repo and call markets, and discuss some features in the relationship between the two markets. Section 3 describes the framework of our empirical analysis on the above relationship. Section 4 reports the results and discusses their implications. Section 5 concludes.

2 Japanese Repo and Call Markets

In this section, we first review some basic facts on the two major short-term, mainly overnight, funding markets in Japan; namely, the call market and the repo market.[2] We also briefly discuss the corresponding facts in other developed countries for the purpose of comparison. We then discuss some features

[1]Other existing studies on Japanese short-term funding markets include Saito, Shiratsuka, and Yanagawa (2005), who examined the effects of seasonal liquidity demand arising from periodic payment practice on the yield curves of money market rates, Fukuda (2010), who examined the spreads between the intraday high and low of the call rate in the zero-interest-rate regime and the quantitative monetary easing policy regime, and Hirose, Ohyama, and Taniguchi (2012), who examined the effects of the Bank of Japan's liquidity provisions on the year-end premium on money market rates.

[2]For details and recent trends in Japanese money markets, see, for example, Toutan Research, Inc. (2009) and Bank of Japan (2014).

of the relationship between the Japanese repo and call markets. Finally, we briefly review recent developments in the implementation of monetary policy by the Bank of Japan.

2.1 The call market

The call market is an interbank money market where financial institutions lend and borrow short-term funds.[3] As for the participants, major banks, foreign banks, and securities companies are mainly on the borrowing side, while trust banks, insurance companies, and investment trusts are mainly on the lending side.

There are two types of call markets in Japan: the uncollateralized call market and the collateralized call market. The collateralized call market is the oldest money market in Japan, which was initially developed more than 100 years ago, although its features have changed over time. In 1985, the uncollateralized call market was introduced as the demand for short-term funding without collateral increased.

In both call markets, there are several types of contract period, from overnight to one year, among which a large volume of transactions are traded overnight. Regarding the settlement cycle, the delivery date of many overnight transactions is set on the same day as the contract (same-day-start or T+0). Many financial institutions make the day's final adjustment of current account balances at the Bank of Japan through T+0 overnight call markets.

The uncollateralized overnight call rate had been the Bank of Japan's target rate for a long time. Before the Bank introduced the "Quantitative and Qualitative Monetary Easing" policy on April 2013 (and except the

[3]Many participants in the call market lend and borrow short-term funds that they possess in their current accounts held at the Bank of Japan, although some participants are not eligible to hold a current account with the Bank.

period during which the Bank conducted a quantitative easing policy from March 2001 to March 2006), the Bank set a target level of the uncollateralized overnight call rate and conducted money market operations on a daily basis in order to encourage the rate to remain at the targeted level.

As shown in Figure 1, the amount outstanding of the call market as a whole was about 20 trillion yen at the end of 2013. This had declined from its peak of around 45 trillion yen in the mid-1990s as short-term interest rates were reduced to a very low, near-zero, level and other short-term funding markets, such as the repo markets, expanded, as discussed later. The amount outstanding of the collateralized call market has been relatively stable and exceeded that of the uncollateralized call market after the financial crisis in 2008 as investors became conservative and shifted their funds from the uncollateralized to the collateralized call market (see, for example, Bank of Japan (2009d), p. 22).

The uncollateralized call market corresponds to the federal funds markets in the US (in which the average overnight rate is the federal funds rate) and the uncollateralized interbank markets in the euro area (in which the average overnight rate is the Eonia). However, collateralized interbank markets like the collateralized call market, which is comparable in size to the uncollateralized call market, are usually not found in other developed countries, as collateralized short-term funds are traded mostly in repo markets.[4]

[4]The collateralized call market and repo market differ in respect to their participants, settlement cycle, and risk control mechanisms. For example, in terms of market participants, while the collateralized call market is an interbank money market, the repo market has a wider range of participants, including non-financial institutions. As for the settlement cycle, while the delivery date of many collateralized call transactions is set on the same day as the contract (T+0), that of many repo transactions is set for the next business day (T+1) as described later. Lastly, while the main risk control mechanism in the collateralized call market is the face value initial haircuts, the repo market has different risk control mechanisms, as we also explain later.

2.2 The repo market

The repo market is an open market where non-financial as well as financial institutions participate and conduct transactions with repurchase agreements,[5] which are contracts that exchange securities, typically government bonds, for funds for a fixed period of time. In fact, there are few non-financial institutions operating in the Japanese repo markets,[6] but compared with the call markets, the repo market participants are more wide ranging. Mainly, securities companies are on the cash-borrowing/securities-lending side, while banks are on the cash-lending/securities-borrowing side in the repo markets.[7]

There are two legal types of repo style transactions in Japan: "Gentan repo (Cash-secured bond lending transaction)" as a loan transaction and "Gensaki repo (Transaction with repurchase agreement)" as a repurchase agreement transaction.[8] In other countries, including the US, the UK, and the euro area, there are also two legal types of repo style transactions: repo transactions and securities lending transactions with cash collateral. How-

[5]As discussed in detail below, repo transactions do not always imply repurchase agreements but may include securities lending transactions in practical terms.

[6]According to statistics compiled by the Japan Securities Dealers Association, the share of non-financial institutions' amount outstanding of repo transactions in the total amount outstanding for the repo market was only 0.4 percent as of December 2013. Although there are no legal or institutional barriers preventing entry to the market, it is costly for many non-financial institutions that do not participate in bilateral repo transactions between financial institutions to build up the necessary internal business framework to conduct repo transactions.

[7]In Japan, many financial institutions, including major securities companies and foreign financial institutions, are eligible to hold a current account with the Bank of Japan. These financial institutions can finalize repo transactions through the Bank. Other participants that do not have a current account with the Bank, including other securities companies and foreign financial institutions without branches in Japan, conduct repo transactions through securities dealers such as banks and major securities companies.

[8]First introduced in 1949, the Gensaki repo market is older than the Gentan repo market which was introduced in 1989 but grew rapidly after several restrictions were removed in 1996. One of the major disadvantages of the Gensaki repo market had been the existence of a securities transaction tax, but even after the government abolished this in 1999 and established new risk control rules in 2001 in order to move this market toward a global standard, the Gensaki repo market has been smaller than the Gentan repo market.

ever, in a narrow sense, "repo" is usually taken to mean transactions based on repurchase agreements, while securities lending with cash collateral is only included in the broad sense of repo transactions.[9] In contrast, Japanese market participants often use the term "repo" to refer to a Gentan repo; that is, securities lending transactions. Anyway, as the functions of the Gentan and Gensaki repo markets are similar, we consider these two types of transactions as being part of the one consolidated repo market in our analysis.[10]

As shown in Figure 2, the amount outstanding of the repo market as a whole (the sum of the Gentan and Gensaki markets) was around 130 trillion yen at the end of 2013. This expanded during the 2000s and became the principal short-term funding market in Japan, as shown in Figure 3.

The securities used in this market include government bonds, local government bonds, and (high-grade) corporate bonds. Nonetheless, more than 99 percent of repo transactions are collateralized by Japan Government Bonds (JGBs) (see Bank of Japan (2014), Box 1). While Special Collateral (SC) repos specify the securities used for lending and borrowing, General Collateral (GC) repos do not. Therefore, while lending/borrowing specific securities is the main purpose of SC repos (for which funds are used as collateral), lending/borrowing funds is the main purpose of GC repos (for which securities are used as collateral). The estimated amount outstanding of GC repos is currently around half of the amount outstanding of the total repo market in Japan.

There are several types of contract period, from overnight to one year, among which a large volume of transactions are traded overnight. Regarding

[9]For details, see Financial Stability Board (2012).

[10]Many previous studies, including Adrian et al. (2013), also treat repo and securities lending with cash collateral as identical transactions because they have the same economic effect. For a detailed comparison of repo and securities lending agreements from a legal perspective, see Ruchin (2011).

the settlement cycle, the delivery date of many overnight GC repo transactions is set on the next business day of the contract (T+1). This T+1 overnight transaction is referred to as tomorrow-next (T/N). Before April 23, 2012, when the settlement cycle for outright purchase/sales transactions of JGBs was shortened to two days, many overnight GC repo transactions were conducted on a T+2 basis, referred to as spot-next (S/N).

As in other developed countries, Japanese repo markets provide several mechanisms intended to control for the various risks related to the transaction, including netting by a central counterparty (CCP) clearing, marking to market, margin calls, haircuts, and the fails practice.[11] Transactions through a CCP, such as the Japan Security Clearing Corporation (JSCC) or the Japan Government Bond Clearing Corporation (JGBCC),[12] cover about half of the total amount outstanding of all repo transactions. Collateral securities are marked to market on a regular basis, although not necessarily on a daily basis, and margin calls are triggered to ensure adequate collateralization of exposures. However, haircuts are set for only a very limited number of repo transactions secured by JGBs.[13] The fails practice has been widely adopted after the financial crisis in 2008, when an unprecedented number of fails took place when Lehman Brothers Japan Inc. went into default, but has not become fully established, and a number of entities still do not accept fails.[14]

[11]For details about the fails practice in Japan, see Bank of Japan (2011).

[12]JGBCC merged with the JSCC on October 1, 2013.

[13]Many market participants commented "since JGBs have maintained a high degree of credibility, it is possible to control risks, through margin calls for example, without setting a haircut" in the Tokyo Money Market Survey conducted in August 2012 (Bank of Japan (2013b)).

[14]According to the Tokyo Money Market Survey conducted in August 2008, more than 50 percent of market participants did not accept the fails practice either because of a lack of understanding of fails, given that they recognized a fail as a debt default, or because their administrative capacity to handle fails was underdeveloped. The number of market participants that accept the fails practice has since increased, and in August 2012, around 80 percent of participants responded that they accepted the fails practice (Bank of Japan (2013b)).

Table 1 summarizes the comparison of the repo markets in Japan, the US, the UK, and the euro area. As shown, the market participants are similar across Japan, the UK, and the euro area, but broader in the US, where not only banks and securities dealers but also hedge funds, money market funds, state and local governments, and other non-financial institutions are major participants (see Copeland et al. (2012), Section 2).[15] The types of securities serving as collateral are also more diverse in the US, where not only government bonds but also agency securities are widely used as collateral,[16] whereas in other countries, government bonds are mainly used. The most actively traded settlement cycle for GC repos in Japan is T+1 overnight (tomorrow-next), while in both the US and the UK, it is T+0 overnight. All repo markets in these countries, more or less, have similar risk control mechanisms, such as netting by a CCP,[17] marking to market, margin calls, haircuts, and the fails practice. Among these, however, mark-to-market valuations are conducted less frequently (not necessarily on a daily basis), and haircuts are rarely observed in Japan. Moreover, the use of third parties to support transactions and to provide collateral management is uncommon in Japan and the UK, while it is common in the US[18] and in the euro area.

[15] In this sense, the US repo market can be divided into two segments: an interdealer or interbank repo segment and a dealer–client repo segment (Financial Stability Board (2012)).

[16] For details, see the 2014 repo market fact sheet (Securities Industry and Financial Markets Association (2014a)).

[17] CCPs currently only cover interdealer repo transactions, while the dealer–client repo segment has not yet been covered in many countries because of regulations or prohibitively high costs.

[18] In the US, tri-party repos support dealer–client repo transactions; for example, repo transactions between securities dealers and other entities. Some custodial banks offer tri-party repo platforms, including transaction support and collateral management, so that these other entities can more easily access the repo market compared with bilateral transactions. In addition, there is another tri-party-style repo platform in the interdealer repo segment, known as the GCF repo. GCF repos support transactions between dealers in the same way and allow dealers to trade anonymously. For details, see Copeland et al. (2012), Sections 2 and 3.

2.3 Relationship between the two markets

Figure 4 depicts the uncollateralized and collateralized overnight call rates and the tomorrow-next (spot-next before April 23, 2012) GC repo rate from 2001 to 2013. As shown, these three rates largely move together because many participants overlap and can arbitrage between these markets. However, there have been persistent differences between these three rates, with the GC repo rate being the highest and the collateralized call rate the lowest. Moreover, those spreads are time variant. In particular, during the recent financial crisis, the GC repo rate sometimes rose sharply while the call rates were relatively stable.

These observed relationships between the Japanese repo and call markets are in sharp contrast to those in many other countries.[19] In particular, the US Treasury GC repo rate has been lower than the federal funds rate, while the spread between them widened during the financial crisis because of the "flight to quality" from the unsecured federal funds market to the secured repo market. As shown in Figure 5, the spreads between the uncollateralized rates and the repo rates in the UK and the euro area as well as in the US widened after the failure of Lehman Brothers in September 2008, while the negative spread between the uncollateralized call rate and the repo rate in Japan moved in the opposite direction and became more negative.

There seem to be at least three possible explanations for why the Japanese GC repo rate has been higher than the uncollateralized call rate, despite the former being secured by collateral. First, there may be some segmentation between the repo and call markets, such that if more creditworthy borrowers move to the latter and only less creditworthy borrowers remain in the

[19]For details of the behavior of repo markets during the financial crisis in developed countries, see Hordahl and King (2008). For those in the euro area, see European Central Bank (2010). For those in the UK, see Jackson and Sim (2013).

repo market, the repo rate will tend to be higher than the call rates. This market segmentation could be deepened by the existence (and significant presence) of the collateralized call market, a secured interbank market that does not exist in other countries, where relatively creditworthy participants borrow funds with collateral. Second, the high transaction costs mainly required by collateral management and risk controls could make repo funding costly. Finally, uncertainty associated with a longer settlement cycle relative to uncollateralized transactions could also make repo funding more costly.

These three factors could also explain why the spread between the Japanese GC repo rate and the uncollateralized call rate widened during the financial crisis.[20] As concerns over counterparty risk increased and some Japanese financial institutions became more cautious in their interbank lending following the failure of Lehman Brothers, the overnight funding rate became polarized by the type of borrower, even within the uncollateralized call market. As illustrated in Figure 6, the highest rate that could be applied to foreign financial institutions increased to about 0.7 percent, while the lowest rate that could be applied to Japanese financial institutions decreased to around 0.1 percent. As a result, most foreign banks were forced to exit from the market, and the amount outstanding in the uncollateralized call market contracted sharply as shown in the upper panel of Figure 7, which might have put some downward pressure on the average uncollateralized call rate. In the meantime, the larger presence of foreign financial institutions in the repo market relative to the call market continued even after the crisis as shown in the lower panel of Figure 7, which led to a widening of the spread between the repo and call rates. In particular, the distress in foreign currency short-term funding markets, as shown in Figure 8, may have put some

[20]For details about the behavior of Japanese financial markets during the financial crisis, see Bank of Japan (2009b, 2009c, 2009d).

upward pressure on the repo rate.

Moreover, an increase in collateral management costs under insufficient risk controls (the second factor mentioned above) and heightened uncertainty associated with a longer settlement cycle (the third factor) also made repo funding more costly during the financial crisis. After Lehman Brothers Japan Inc. filed for bankruptcy, some market participants that were cautious about incurring costs associated with risk controls, including settlement fails, avoided repo transactions. Under these circumstances of heightened uncertainty, Japanese major banks, the main fund suppliers in the repo market, became reluctant to undertake arbitrage transactions, which led to a widening of the spread and a weakening of the link between the repo and call rates (see Bank of Japan (2009c), Chapter II-1).

In the empirical analysis below, we quantitatively examine the relationship between Japanese GC repo and the uncollateralized call rates, including the above features.

2.4 Monetary policy implementation

Before moving to the empirical analysis, we briefly review recent developments in monetary policy implementation by the Bank of Japan.

Until 1999, the Bank of Japan conducted monetary policy in a conventional way; that is, the Bank set a positive (non-zero) target level for the uncollateralized overnight call rate and conducted money market operations on a daily basis to encourage the rate to remain at the targeted level. The main tool for short-term funds-supplying/absorbing operations at the time was the purchase/sale of bills, among which the purchase of bills was replaced by funds-supplying operations against pooled collateral in 2006. Besides these, "Repo operations" began to be used as another tool for money market opera-

tions in 1997. Following the reformation of the Gensaki repo market in 2001, this operation was replaced by the purchase/sale of Japanese Government Securities with repurchase agreements, or "Gensaki operations," in 2002.

In February 1999, the Bank first introduced a zero-interest-rate policy by announcing that it would encourage the uncollateralized overnight call rate to move "as low as possible," which lasted until August 2000. Then in March 2001, after a short-lived normalization period, the Bank introduced a quantitative easing policy by changing the main operating target for money market operations from the uncollateralized overnight call rate to the outstanding balance of current accounts held at the Bank. Under this policy, the uncollateralized overnight call rate stayed at effectively zero. In March 2006, after the year-on-year change in the consumer price index became positive, the Bank decided to exit from the quantitative easing policy by changing the operating target from the outstanding balance of current accounts to the uncollateralized overnight call rate, but the target rate was set at "effectively zero percent." Four months later in July 2006, the Bank decided to raise the target rate from zero to 0.25 percent and finally exited from the zero-interest-rate policy.

After the failure of Lehman Brothers in September 2008, the Bank started to cut the target rate again. However, the uncollateralized overnight call rate did not fall to zero, even after the Bank set the target rate at "0 to 0.1 percent" in October 2010, mainly because the complementary deposit facility was introduced in November 2008 and the interest rate paid on excess reserves under the facility was held at 0.1 percent. In the meantime, the Bank introduced various operation tools and unconventional measures in order to further enhance monetary easing and get over the long-lasting deflation. In December 2009, a new funds-provisioning operation with a fixed rate, set

to 0.1 percent, was introduced to encourage a further decline in longer-term interest rates in the money market. In October 2010, the "Comprehensive Monetary Easing" policy, including the Asset Purchasing Program was introduced.

In April 2013, the Bank introduced the "Quantitative and Qualitative Monetary Easing" policy in place of the Comprehensive Monetary Easing policy, to achieve the price stability target of 2 percent. Under this policy, the main operating target for money market operations was changed from the uncollateralized overnight call rate to the monetary base.

3 Empirical Analysis

In this section, we describe the framework of our empirical analysis, including the system of equations, our estimation strategy, and the explanatory variables. Before this, we first check the statistical relationship between the primary data used in our analysis; i.e., Japanese repo and call rates.

3.1 Data on repo and call rates

In our analysis, we use daily data on Japanese repo and call rates from July 14, 2006 to April 3, 2013. The start date is when the Bank of Japan exited from the zero-interest-rate policy and raised the target rate from 0 to 0.25 percent. The end date is set immediately before the Bank introduced the Quantitative and Qualitative Monetary Easing policy on April 4, 2013. The call rate that we use is the uncollateralized overnight call rate, which had been used as the Bank's target rate during our sample period. The rate is calculated as the value-weighted average interest rate at which funds are received and paid on a contract day (T+0) and reverse transactions

are conducted on the business day following the contract day.[21] The repo rate that we use is the tomorrow-next (spot-next before April 23, 2012, as explained in Section 2) General Collateral (GC) repo rate. The rate, known as the "Tokyo Repo Rate," is calculated as the reference institutions average rate by the Bank of Japan until 2012 and thereafter by the Japan Securities Dealers Association.[22]

As shown in Figure 9, these two rates appear to move together, and thus there could be a cointegrating relationship between them. Moreover, there seem to be some distinct regimes for the relationship in our sample period before, during, and emerging from the financial crisis. In order to check these possibilities, we conduct unit root and cointegration tests over three periods: from July 14, 2006 to July 10, 2007; from February 21, 2007 to December 30, 2008; and from January 5, 2009 to April 3, 2013. The first is a pre-crisis period that includes two policy changes to raise the target rate and ends one month before the outbreak of the BNP Paribas shock in August 2007. The second is a mid-crisis period that starts on the day of the Bank of Japan's last rate hike before the crisis and ends on the last business day of 2008, when the Bank smoothly conducted its year-end open market operations following the rate cut to 0.1 percent on December 19. These two periods slightly overlap in order to maintain the sample size for our empirical analysis.[23] The last is a post-crisis period that starts on the first business day of 2009, during which the policy target rate had been kept almost unchanged except that it was changed from 0.1 percent to "0 to 0.1 percent" on October 5, 2010.

[21]The daily data on the uncollateralized overnight call rate is available from the Bank of Japan's website.

[22]Daily data on the Tokyo Repo Rate are available from the Japan Securities Dealers Association's website.

[23]We tried some different divisions into sub-periods, but the results of the tests for unit root and cointegration are generally unchanged.

Tables 2 and 3 summarize the results of the tests for unit roots and cointegration, respectively. According to the augmented Dickey–Fuller test, as shown in Table 2, the null of a unit root is not rejected for the first two periods, while the null is rejected for the last period. For the first two periods, the Johansen test reveals that the repo and call rates are cointegrated, as shown in Table 3. Therefore, a cointegrating relationship between the two rates is found in both the pre-crisis and mid-crisis periods in Japan but not in the post-crisis period. These results are similar to those of Bech, Klee, and Stebunovs (2012) in the US.

3.2 Empirical framework

Following Bech, Klee, and Stebunovs (2012), we conduct an empirical analysis of the relationship between the Japanese GC repo rate and the uncollateralized call rate using a vector error correction model. Using this framework, we can analyze the strength of the link between the two rates, the background of discrepancy between them, and various factors that affect each rate, including changes in the policy target rate and the current account balances at the Bank of Japan, institutional changes in the payment system, and various policy and market events.

The model with a cointegrating relationship for the pre-crisis and mid-crisis periods can be expressed as follows:

$$\begin{aligned} \Delta\, call_t &= \alpha_c(repo_{t-1} - \beta_1 call_{t-1} - \beta_0) \\ &\quad + \Phi_{cc}(L)\Delta\, call_t + \Phi_{cr}(L)\Delta\, repo_t + \gamma_c\, m_t + e_{c,t} \qquad (1) \\ \Delta\, repo_t &= \alpha_r(repo_{t-1} - \beta_1 call_{t-1} - \beta_0) \\ &\quad + \Phi_{rc}(L)\Delta\, call_t + \Phi_{rr}(L)\Delta\, repo_t + \gamma_r\, m_t + e_{r,t} \qquad (2) \end{aligned}$$

where $call_t$ is the uncollateralized call rate, $repo_t$ is the GC repo rate, and Δ is the one-period (business day) difference operator. L is the lag operator, and we use five lags of all interest rate terms, comprising both autoregressive and cross-regressive terms, as suggested by the Schwarz Information Criterion (SIC) test.[24] m_t denotes the vector of exogenous variables considered in the next subsection, and $e_{c,t}$ and $e_{r,t}$ are error terms, which we specify as generalized autoregressive conditional heteroscedasticity (GARCH) and threshold ARCH (TARCH) processes as described below. α's, β's, γ's, and Φ's are parameters to be estimated, among which the α's represent the speed of adjustment of the error correction terms.

Similarly, the model without a cointegrating relationship for the post-crisis period can be expressed as follows:

$$call_t = \mu_c + \Phi_{cc}(L)call_t + \Phi_{cr}(L)repo_t + \gamma_c\, m_t + e_{c,t} \quad (3)$$

$$repo_t = \mu_r + \Phi_{rc}(L)call_t + \Phi_{rr}(L)repo_t + \gamma_r\, m_t + e_{r,t} \quad (4)$$

where μ_c and μ_r are constant terms to be estimated.

To allow for the possibility of heteroscedasticity in the error terms, we formulate the variance and covariance processes with GARCH and TARCH components as follows:

$$h_{cc,t} = c_c + a_c\, e^2_{c,t-1} + d_c\, I^-_{c,t-1} e^2_{c,t-1} + b_c\, h_{cc,t-1} \quad (5)$$

$$h_{rr,t} = c_r + a_r\, e^2_{r,t-1} + d_r\, I^-_{r,t-1} e^2_{r,t-1} + b_r\, h_{rr,t-1} \quad (6)$$

$$h_{cr,t} = \rho_{cr} \sqrt{h_{cc,t} h_{rr,t}} \quad (7)$$

where $h_{cc,t}$ and $h_{rr,t}$ are the conditional variances of $e_{c,t}$ and $e_{r,t}$, respec-

[24] The optimal lag length based on the SIC test varies among autoregressive and cross-regressive terms, but we select a more parsimonious and balanced specification rather than setting the optimal lag length for each term.

tively. $h_{cr,t}$ is the conditional covariance between $e_{c,t}$ and $e_{r,t}$ with a constant conditional correlation (CCC) coefficient, ρ_{cr}, which is formulated following Bollerslev (1990). $I^-_{c,t-1}$ and $I^-_{r,t-1}$ are indicators of the TARCH components that equal one if the corresponding error term was negative in the previous period.

We estimate the above models with system GARCH and TARCH errors, using maximum likelihood with Bollerslev–Wooldridge robust standard errors (Bollerslev and Wooldridge, 1992).[25]

3.3 Exogenous variables

Given the above framework, we consider various exogenous variables (m_t in the above models) that likely affect the Japanese GC repo rate and the uncollateralized call rate on a daily basis. These may include variables related to monetary policy changes, the liquidity effects, changes in market sentiment and trading volume, institutional changes in the payment system, and calendar and specific events.

First, changes in the policy target rate ($\Delta\, target$) definitely affect the uncollateralized call rate and possibly also the GC repo rate. On the other hand, the amount of successful bids for Japanese Government Securities purchasing operations with repurchase agreements (Gensaki operation, *gensaki*) may naturally affect the GC repo rate and possibly the uncollateralized call rate as well.[26] Besides these, we use dummy variables to indicate the change

[25]The error correction term in the model with cointegrating relationship is estimated using ordinary least squares before the maximum likelihood estimation and included as an independent variable in the vector error correction model with system GARCH and TARCH errors.

[26]The Gensaki operations could contribute more directly to stabilizing the repo market because most counterparties are securities companies equipped to participate in repo transactions. To capture such a more direct effect on the spot-next GC repo rate in our estimation, we use only the Gensaki operation with overnight maturity on a T+2 settle-

in the unit for bid rates in competitive yield auctions for money market operations (July 24, 2006), the introduction of measures to improve liquidity in the repo market (October 14, 2008), the funds-provisioning operation with a fixed rate (December 1, 2009), and the "Comprehensive Monetary Easing" policy (October 5, 2010).

Regarding the effects of changes in the current account balances at the Bank of Japan on short-term interest rates, which are referred to as the liquidity effects, we need to identify an exogenous shift to the current account balances because the Bank can largely control the supply of reserves in order to achieve the target rate on a daily basis. Following Hamilton (1997) and Uesugi (2002), we use the central bank's forecast error of the daily reserve balances as the exogenous shift factor. Specifically, we calculate the forecast errors from the Bank of Japan's daily projections of "Treasury funds and others" in the sources of changes in the current account balances and use it as an exogenous instrumental variable ($\Delta\, bojca$) in our model.[27] These forecast errors had been very small compared with the total amount of current account balances during our sample period, but they acted as a major factor in the unexpected changes in the balances. In the meantime, there may be similar liquidity effects specifically affecting the repo rate, but we could not identify

ment (spot-next) basis, which had been implemented every business day since November 13, 2008 as an exogenous variable.

[27]There are two sources (autonomous factors) of changes in current account balances at the Bank of Japan: "Banknotes" and "Treasury funds and others." We use the forecast error of only the latter as an instrument because it is more strongly correlated with unexpected changes in the current account balances than the forecast error of the former ("Banknotes") factor. In addition, as discussed later, the forecast error of "Treasury funds and others" could possibly capture the liquidity effects on the repo rate as well as the call rate. The results using the forecast error of the sum of "Banknotes" and "Treasury funds and others" as an instrument are not very different from the results shown in this paper. Uesugi (2002) used the forecast error of only the "Banknotes" factor as an instrument because the projection method of "Treasury funds and others" adopted by the Bank of Japan in his sample period caused an endogeneity problem, but that problem has been solved under the currently adopted projection method.

an appropriate instrument that could capture exogenous shifts in the supply of repo money. The forecast errors of "Treasury funds and others" included in our model could possibly capture these liquidity effects on the repo rate as well because some of these errors relate to the market conditions for JGBs.

Next, we consider the variables related to the risk sentiment of market participants and market trading volume. Risk sentiment critically affected short-term funding markets during the financial crisis, and rapid changes in trading volume during the crisis also appeared to affect market rates exogenously. Regarding risk sentiment, we include the 3-month Libor–OIS spreads for both the Japanese yen ($\Delta\, spread_1$) and the US dollar ($\Delta\, spread_2$) among our exogenous variables. The latter widened much more drastically than the former during the crisis, as shown in Figure 8 and discussed in Section 2, and could directly affect Japanese short-term funding markets. Besides these, we also use a dummy variable indicating the implementation of Basel II (March 30, 2007), which could have influenced the risk-management behavior of market participants.[28] As for trading volume, we use the lagged changes in the amount outstanding of the uncollateralized call market ($\Delta\, market$). As shown in Figure 7 and discussed in Section 2, this market contracted sharply during the crisis, as most foreign banks were forced to exit from the market, and this could exogenously affect the call rate. Unfortunately, there are no available daily data on the amount outstanding in the repo market, and we were unable to find other appropriate exogenous variables that could adequately capture repo market volume.

We also consider the effects of institutional changes in the payment system

[28] Under Basel II, when the value of collateral submitted (mark-to-market value) exceeds the amount of funds borrowed, the borrower must recognize the excess portion of the collateral as a credit risk exposure. When this rule was implemented, there was a concern about a decline in the demand for collateralized short-term funding, especially in the collateralized call market.

during our sample period. We use dummy variables indicating the launch of phase 1 of the next-generation real-time gross settlement (RTGS-XG) project of the BOJ-NET Funds Transfer System (October 14, 2008), the launch of phase 2 of the RTGS-XG project (November 14, 2011),[29] and shortening of the settlement cycle to two days for outright purchase/sales transactions of JGBs (April 23, 2012). We use a single dummy variable to indicate phase 1 of the RTGS-XG project and the Bank of Japan's measures to improve liquidity in the repo market, as they were introduced on the same day.

Finally, we consider several calendar and other specific-event factors. We use dummy variables for the month-end, quarter-end, year-end, and fiscal year-end business days. Given that the settlement cycles for the call and repo markets differ, we use separate dummy variables for these calendar factors in the call and repo rate equations. Other than these, we use dummy variables to indicate the (final) days of the Bank of Japan's monetary policy meetings and the next business day (March 14, 2011) of the Great East Japan Earthquake.[30]

4 Results

In this section, we report the results of the empirical analysis over the three sub-periods and discuss their implications, including the background of some of the features observed in the relationship between the Japanese repo and

[29]For details of the RTGS-XG project, see Bank of Japan (2009a, 2013a).

[30]On Monday, March 14, 2011, lenders in the money market held back their funds provisions amid a very strong sense of uncertainty caused by the inability to gauge fully the effects of the disaster, and thus it became extremely difficult to undertake transactions. The Bank of Japan took various measures to cope with the situation, including same-day funds-supplying operations on six consecutive business days between March 14 and 22. As a result, money market transaction volumes gradually began to recover, and short-term interest rates were generally stabilized at low levels. In particular, the uncollateralized call rate fell to lower than its pre-earthquake level for several months.

call rates discussed in Section 2.

4.1 Pre-crisis period: 2006–2007

Table 4 presents the results for the pre-crisis period from July 14, 2006 to July 10, 2007. First, the estimated cointegration vector implies that the long-run relationship between the GC repo rate and the uncollateralized call rate is close to one-to-one (the slope coefficient is 0.929), and the former is higher than the latter by 8.5 basis points in the long run.

The error correction coefficients with respect to the call rate (α_c) and the repo rate (α_r) are both significant with correct signs. Comparing their absolute values, we can see that the repo rate is more strongly adjusted to restore the cointegrating relationship, which is consistent with the functioning of a transmission mechanism from the call to the repo rate. At the same time, however, the cross-market lags from the call to the repo rate as well as those from the repo to the call rate are mostly insignificant, while the own lags of the two rates are more significant.

During this period, there were two policy changes to raise the target rate: that from 0 to 0.25 percent on July 14, 2006 and that from 0.25 to 0.5 percent on February 21, 2007. These policy changes significantly affected the call rate, while their direct effects on the repo rate were statistically insignificant. The change in unit for bid rates in competitive yield auctions for money market operations on July 24, 2006 also significantly raised the call rate in a way that facilitates the rate hike.

Regarding the liquidity effect, the Bank of Japan's forecast errors of "Treasury funds and others" significantly affected the call rate, while their effects on the repo rate were insignificant. According to the estimated coefficient, a one trillion yen increase in the forecast error leads to a 1.7 basis

point decrease in the call rate. This size of the liquidity effect is within the range estimated by Uesugi (2002), who reports the corresponding estimate to be on average around a 6.6 basis point decrease in the call rate.[31]

Regarding the effects of changes in market sentiment and volume, the Libor–OIS spreads and the lagged changes in the amount outstanding of the uncollateralized call market did not significantly affect either the call rate or the repo rate. The effects of the dummy variable for the implementation of Basel II on March 30, 2007 were also insignificant. These results may be consistent with the fact that short-term funding markets were relatively calm during this period.

Finally, many of the calendar factors significantly affected both the call and repo rates. Regarding the variance and covariance processes, the ARCH, GARCH, and TARCH terms were all insignificant for the conditional variance of the error term in the repo equation, and only the GARCH term was significant for that in the call equation.

4.2 Mid-crisis period: 2007–2008

Since the US housing prices began to fall from their 2006 peak and subprime mortgage-related losses were reported by the world's major financial institutions in early 2007, awareness of the downside risks to the global financial markets gradually increased. In the meantime, the Bank of Japan held its target rate at the 0.5 percent to which it had raised it on February 21, 2007.

[31] The range estimated by Uesugi (2002) is from an 88 basis point decrease to a 37 basis point *increase* in the call rate as the effect of a one trillion increase in the forecast error. Our estimate, a 1.7 basis point decrease, may be comparable to his average estimate, 6.6 basis point decrease, given that the "Treasury funds and others" factor in our sample period was more than three times larger than the "Banknotes" factor that the forecast error used by Uesugi (2002) was based on in his sample period. Note that he, unlike us, defines the forecast error as the predicted value minus the realized value; therefore, the signs of his estimates mentioned above are opposite to those in his paper.

With the heightening of the financial crisis after the collapse of Lehman Brothers in September 2008, the Bank cut the target rate twice: from 0.5 to 0.3 percent on October 31 and from 0.3 to 0.1 percent on December 19, 2008. Table 5 presents our estimation results for this mid-crisis period from February 21, 2007 to December 30, 2008.

The estimated cointegration vector reveals that the long-run relationship between the GC repo rate and the uncollateralized call rate weakened in the sense that the slope coefficient declined to 0.675 (from 0.929 in the pre-crisis period). At the same time, the estimated error correction coefficient with respect to the call rate (α_c) became insignificant with the wrong sign, and the coefficient with respect to the repo rate (α_r), while still significant, declined substantially to -0.052 (from -0.129) in absolute terms. These results imply that the link between the two rates weakened remarkably in the mid-crisis period.[32]

Meanwhile, the changes in the policy target rate, which were the two rate cuts in this period mentioned earlier, significantly affected the repo rate as well as the call rate. Moreover, the amount of successful bids for spot-next Gensaki operations, which had been implemented every business day since November 13, 2008, also significantly lowered the repo rate and the call rate. These results imply that the Bank of Japan's policy actions directly affected the GC repo rate and prevented it from staying high and deviating far from the call rate. In the meantime, the liquidity effect on the call rate remained significant, although the size in absolute terms shrank slightly to -0.013 (from -0.017 in the pre-crisis period), and the effect on the repo rate was insignificant.

Regarding the effects of changes in market sentiment, the US dollar Libor–

[32] According to the Chow breakpoint tests, the null hypotheses of no break at and around July 10, 2007 is rejected at less than the one percent level of significance.

OIS spread significantly affected the repo rate, while the effects of the yen Libor–OIS spread were still insignificant. As the former drastically widened in the mid-crisis period, its upward pressure on the repo rate was substantial. For instance, according to our estimation results, the massive expansion of the dollar Libor–OIS spread by 36.8 basis points on September 25, 2008 explained about a half of the increase in the Japanese GC repo rate on the following day. This result is in sharp contrast with the results using the US data (Bech, Klee, and Stebunovs, 2012), where the expansion of the dollar Libor–OIS spread pushed the US repo rate down while it pushed the federal funds rate up.[33] A large presence of foreign financial institutions in the repo market, as discussed in Section 2, led to a rise in the repo rate, rather than a decrease, in response to the distress in the dollar short-term funding markets. At the same time, the rapid shrinkage of the uncollateralized call market due to the exit of foreign banks as borrowers of funds appears to have placed some downward pressure on the call rate, although the effect was insignificant.

Regarding the effects of institutional changes in the payment system, the dummy variable for the launch of phase 1 of the RTGS-XG project of the BOJ-NET Funds Transfer System on October 14, 2008 significantly lowered the repo rate, although this dummy variable also captured the effect of measures to improve liquidity in the repo market introduced by the Bank of Japan on the same day. Regarding the calendar factors, many of them significantly affected both the call and repo rates, as they did in the pre-crisis period.

Finally, regarding the variance and covariance processes, in contrast to the pre-crisis period, the ARCH, GARCH, and TARCH terms were all sig-

[33] An empirical analysis using the Euro interbank repo market data (Mancini, Ranaldo, and Wrampelmeyer, 2014) shows that the expansion of the Euro Libor–OIS spread pushes the Euro repo rate down.

nificant for the conditional variance of the error term in the repo equation. In particular, the estimated TARCH term implies that news to raise the repo rate (a positive regression error) tended to increase its volatility more than did news to reduce the repo rate. On the other hand, only the ARCH term was significant for the conditional variance of the error term in the call equation.

4.3 Post-crisis period: 2009–2013

Since the Bank of Japan cut the target rate to 0.1 percent on December 19, 2008, the rate had been kept almost unchanged (except that it was changed to "0 to 0.1 percent" on October 5, 2010), while some unconventional measures including the Asset Purchase Program were introduced.[34] The overnight uncollateralized call rate had still been used as the Bank's policy target rate until the end of our sample period, which was immediately before the Bank introduced the Quantitative and Qualitative Monetary Easing policy on April 4, 2013. Table 6 presents our estimation results for this post-crisis period from January 5, 2009 to April 3, 2013.

For this period, the null of a unit root is rejected, and as a result, the two rates are no longer cointegrated. Therefore, we estimate the model without a cointegrating relationship expressed as equations (3) and (4). While the long-run relationship between the GC repo rate and the uncollateralized call rate has disappeared, some of the cross-market lags as well as the own lags for the two rates remain strongly significant, although the estimated coefficients are much smaller than those of the own lags.

While there had been almost no changes in the target rate during this

[34]The interest rate paid on excess reserve balances under the complementary deposit facility, which was introduced on November 16, 2008, had also been held at 0.1 percent.

period, the introduction of the funds-provisioning operation with a fixed rate on December 1, 2009 significantly lowered the repo rate, and the introduction of the "Comprehensive Monetary Easing" (which included the change in the target rate from 0.1 percent to "0 to 0.1 percent") on October 5, 2010 significantly lowered both the call and repo rates. Moreover, the amount of successful bids for spot-next Gensaki operations significantly lowered the call rate but not the repo rate. However, the liquidity effect on the call rate as well as the repo rate was no longer significant as the current account balances at the Bank of Japan expanded more than threefold during this period.

The effects of changes in market sentiment captured by the Libor–OIS spreads were no longer significant during this period. In the meantime, the lagged changes in the amount outstanding of the uncollateralized call market, which had already declined after most foreign banks exited from the market during the mid-crisis period, significantly affected the call rate in this post-crisis period. The positive relationship between the market volume and the rate may capture the effects of temporary fluctuations in the short-term funding demand, such as borrowing by some financial institutions to test their funding conditions, under the relatively calm market conditions.

Regarding the effects of institutional changes in the payment system, neither the launch of phase 2 of the RTGS-XG project on November 14, 2011 nor the shortening of the settlement cycle to two days for outright purchase/sales transactions of JGBs on April 23, 2012 significantly affected either the repo rate or the call rate. Regarding the calendar factors, many of them, but slightly fewer than in the pre- and mid-crisis periods, significantly affected the call and repo rates. In the meantime, the Great East Japan Earthquake on March 11, 2011 significantly raised both the call and repo rates on the following business day.

Finally, regarding the variance and covariance processes, the TARCH and GARCH terms were significant for the conditional variance of the error term in the repo equation, and the ARCH and TARCH terms were significant for those in the call equation. Interestingly, the estimated TARCH terms in both equations imply that news to *reduce* the repo and call rate (a negative regression error) tended to increase their volatility more than did news to raise the repo rate, in contrast to the mid-crisis period. In particular, the large negative regression error in the repo equation during this period had been caused by a temporary supply shortage of Treasury discount bills (T-bills) and market expectations of even stronger monetary easing, including a lowering of the interest rate paid on excess reserves.

4.4 Summary of the results

In closing this section, we briefly summarize the main results of our empirical analysis over the three sub-periods and discuss their implications.

We found that the relationship between the Japanese repo and call rates changed over the three sub-periods before, during, and emerging from the financial crisis. In particular, the estimated long-run relationship (as represented by the slope coefficient) and the short-run adjustment (the error correction coefficients) substantially weakened in the mid-crisis period. These results are generally consistent with the facts and features discussed in Section 2. The weakening of the long-run relationship may be related to the fact that segmentation between the two markets deepened as most foreign banks were forced to exit from the call markets. In this regard, we also obtain the result that the massive expansion of the US dollar Libor–OIS spread during this period put substantial upward pressure on the repo rate, which may capture the large presence of foreign financial institutions in the repo market

that continued even after the crisis. In the meantime, the weakening of the short-run adjustment in the mid-crisis period may be related to the fact that Japanese major banks became reluctant to undertake arbitrage transactions between the two markets.[35]

At the same time, we also found from our analysis that the Bank of Japan's policy actions in the mid-crisis and post-crisis periods had been effective to some extent in lowering both the repo and call rates, and stabilizing the relationship between them. In the mid-crisis period, the spot-next Gensaki operations as well as the cuts in the target rate prevented the repo rate from staying high and deviating far from the call rate. In the post-crisis period, the introduction of the funds-provisioning operation with a fixed rate and the "Comprehensive Monetary Easing" significantly lowered the repo rate. In the meantime, the liquidity effect on the call rate was significant in the mid-crisis period as well as the pre-crisis period but became insignificant in the post-crisis period as the current account balances at the Bank of Japan expanded.

Regarding the effects of institutional changes in the payment system, the launch of phase 1 of the RTGS-XG project of the BOJ-NET Funds Transfer System on October 14, 2008 could have lowered the repo rate (which is unclear because the Bank of Japan introduced measures to improve liquidity in the repo market on the same day), but the launch of phase 2 of the RTGS-XG project on November 14, 2011 and the shortening of the settlement cycle to two days for outright purchase/sales transactions of JGBs on

[35]Bech, Klee, and Stebunovs (2012) also report the result that the error correction coefficient with respect to the repo rate declined in absolute terms from the pre-crisis to the mid-crisis period using the US data. As background to their result, Bech, Klee, and Stebunovs (2012) mention the fact that some investors were willing to leave arbitrage opportunities unexploited because of credit concerns, especially in the unsecured federal funds market. In the meantime, the slope coefficient in the cointegration vector changed little from the pre-crisis to the mid-crisis period in their results.

April 23, 2012 did not significantly affect the repo rate. The last result may imply that a longer settlement cycle of repo transactions in Japan relative to uncollateralized transactions, which is mentioned in Section 2, is not a very important factor in explaining the spread between the repo rate and the uncollateralized call rate.

Finally, from the estimated TARCH component in the variance and covariance processes, we found that news to raise the repo rate tended to increase its volatility more than news to reduce the repo rate did during the mid-crisis period, but this tendency reversed in the post-crisis period.

5 Concluding Remarks

In this paper, we investigated empirically the relationship between the Japanese GC repo rate and the uncollateralized call rate and found that the relationship had changed before, during, and emerging from the financial crisis. The results of our empirical analysis suggested that segmentation between the Japanese repo and call markets was one of the key factors explaining some features in the relationship between the two rates. The analysis also revealed how much changes in the policy target rate and the current account balances at the Bank of Japan, institutional changes in the payment system, and various policy and market events affected both the repo and call rates.

From our analysis in this paper, at least two extensions could be pursued. The first is an extension of the sample period to the period following the introduction of the Quantitative and Qualitative Monetary Easing policy. This extension could also enable some simulations for a possible future exit from that policy.[36] For these purposes, however, several additional elements should

[36]Bech, Klee, and Stebunovs (2012) conduct simulation exercises using their estimation results to illustrate the possible effect of reserve-draining operations by the US Federal

be considered, including the interest rate paid on excess reserves and the size of the Bank of Japan's balance sheet. Another extension would be a more detailed consideration of market structure and institutions. In the current analysis, only limited data were available on a daily basis, especially those identifying the structure of the repo market. Nevertheless, such an extension would be useful, as various measures to enhance the market infrastructure have been examined and implemented.

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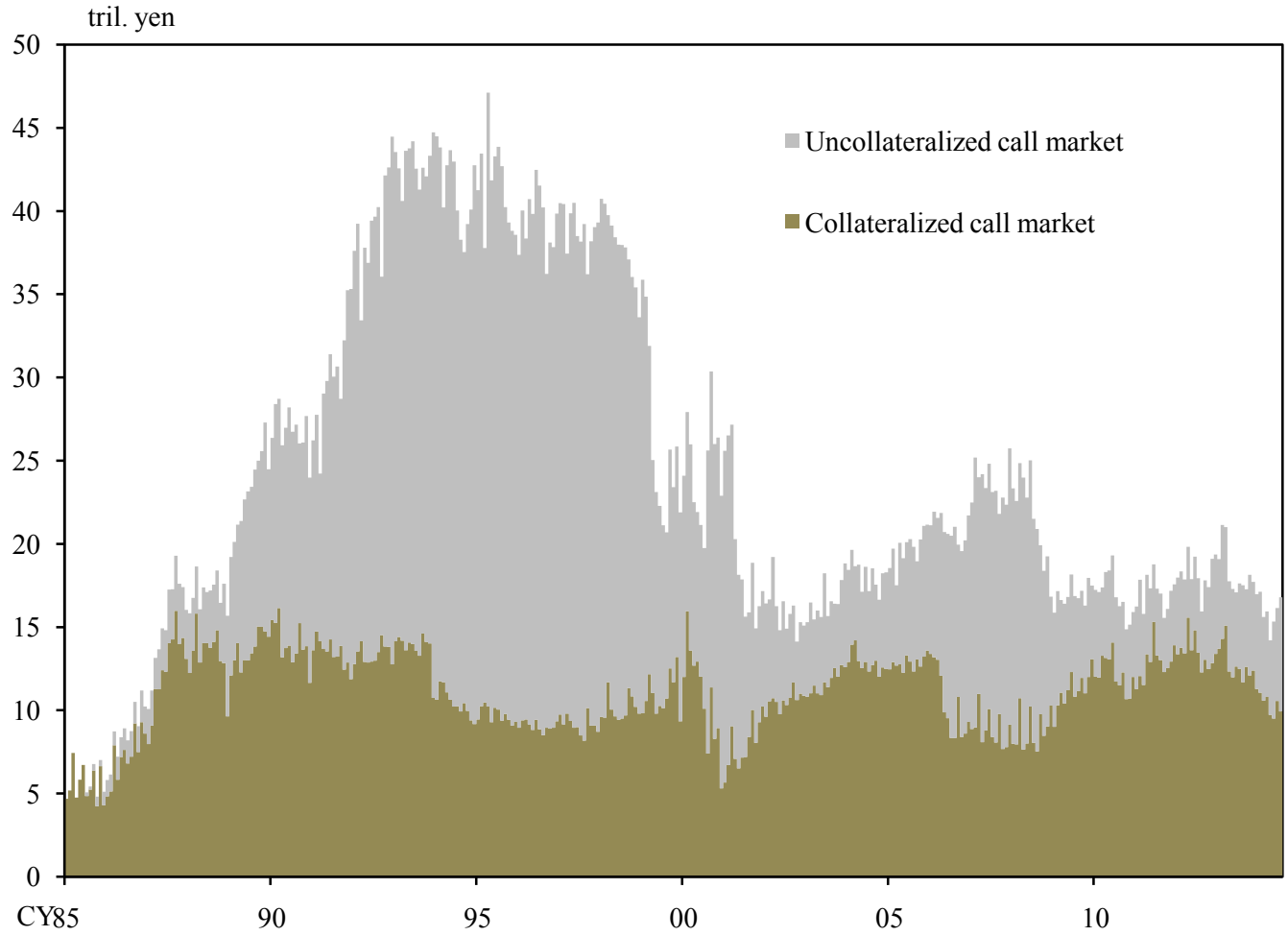
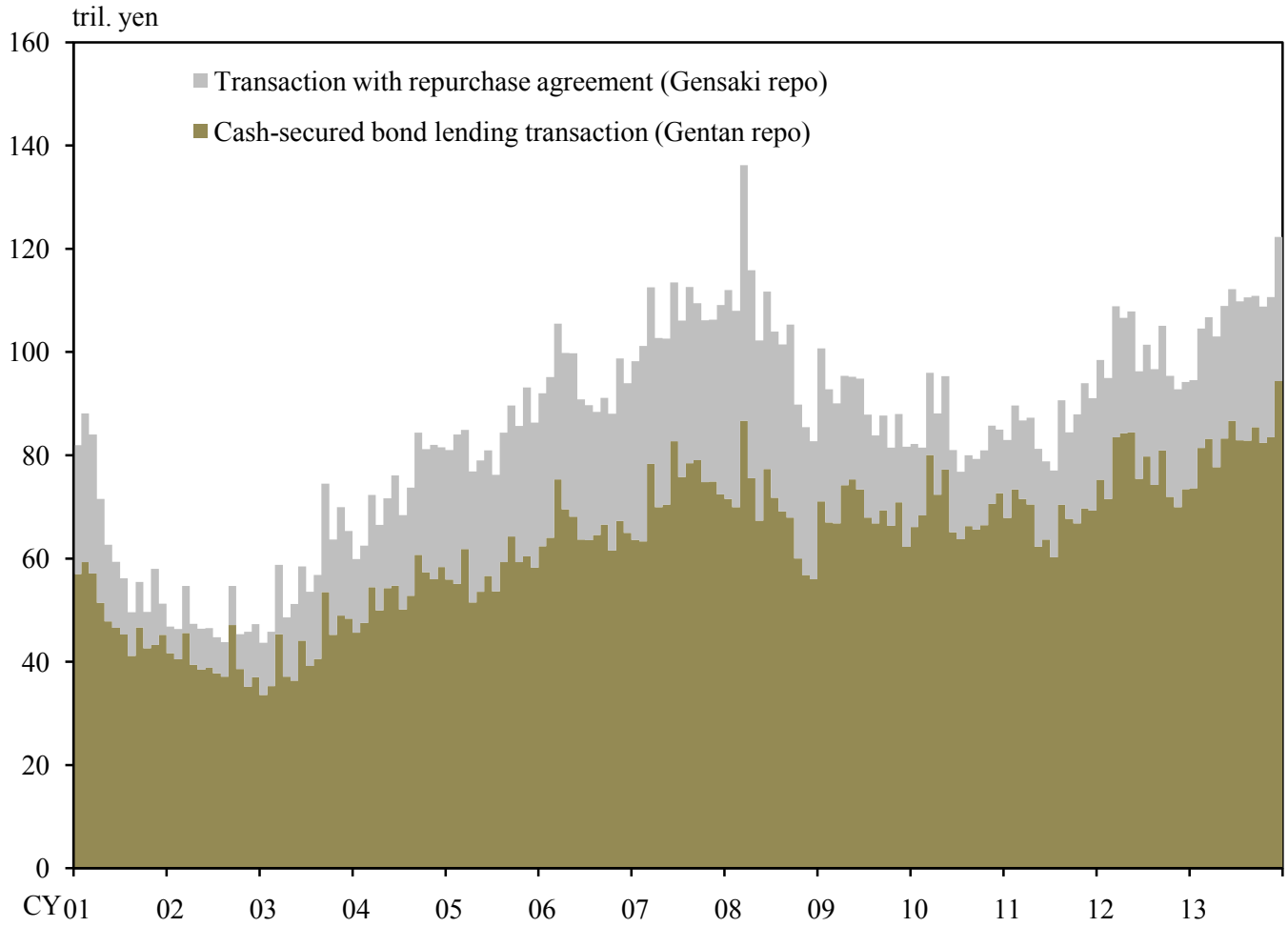
Figure 1: Amounts outstanding of the Call market



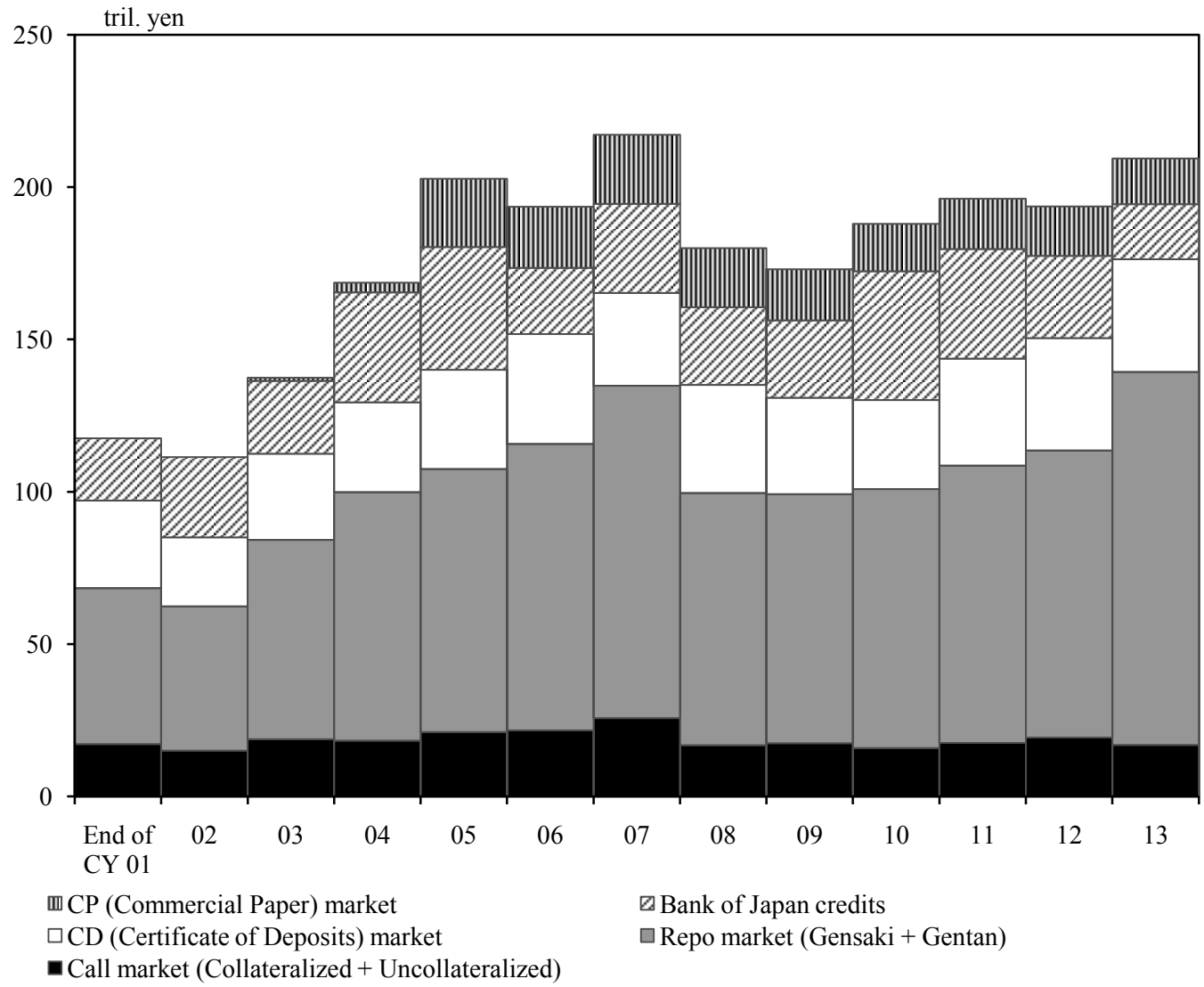
Source: Bank of Japan.

Figure 2: Amounts outstanding of the Repo market



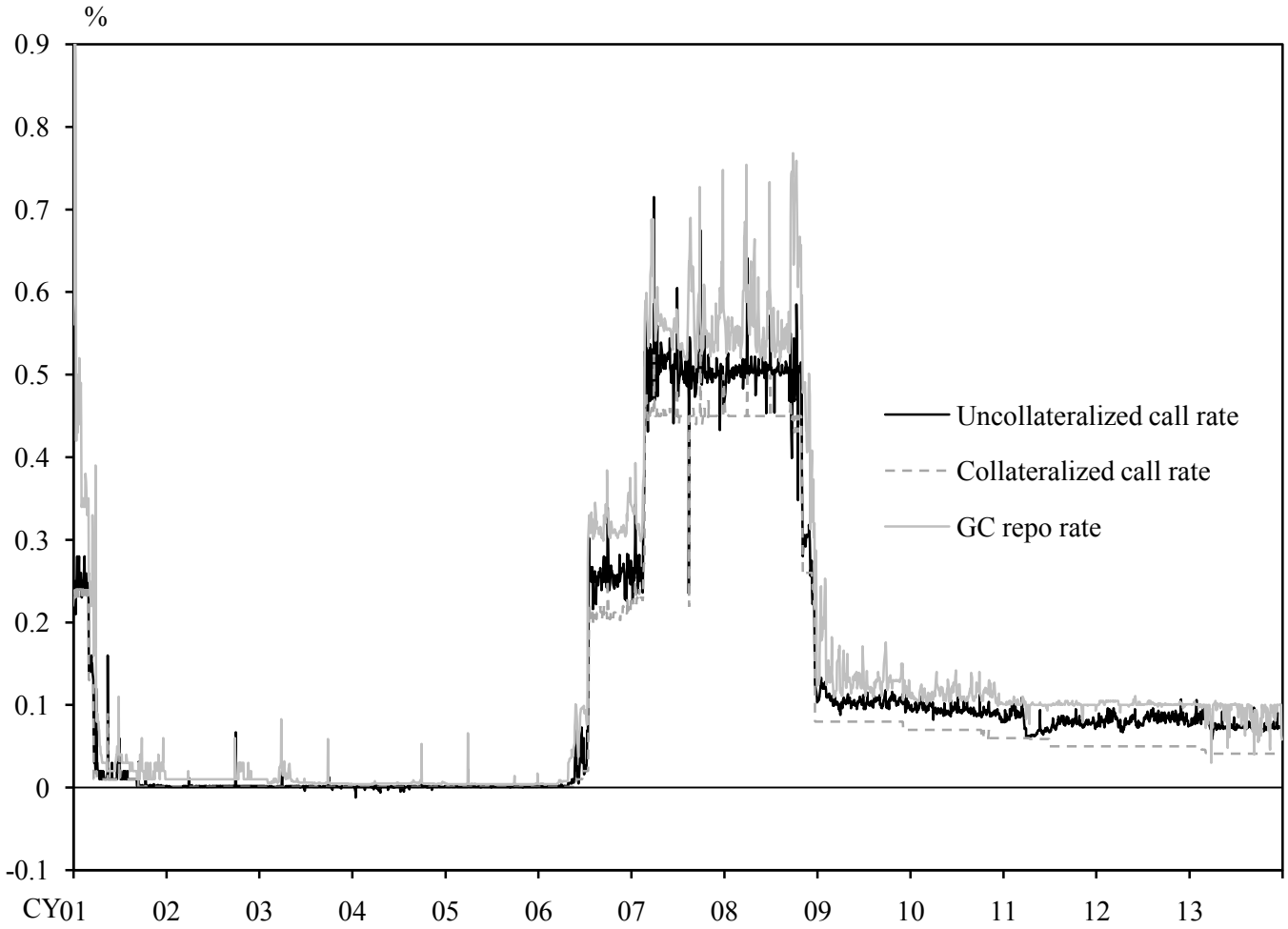
Source: Japan Securities Dealers Association.

Figure 3: Amounts outstanding of Short-term financial market



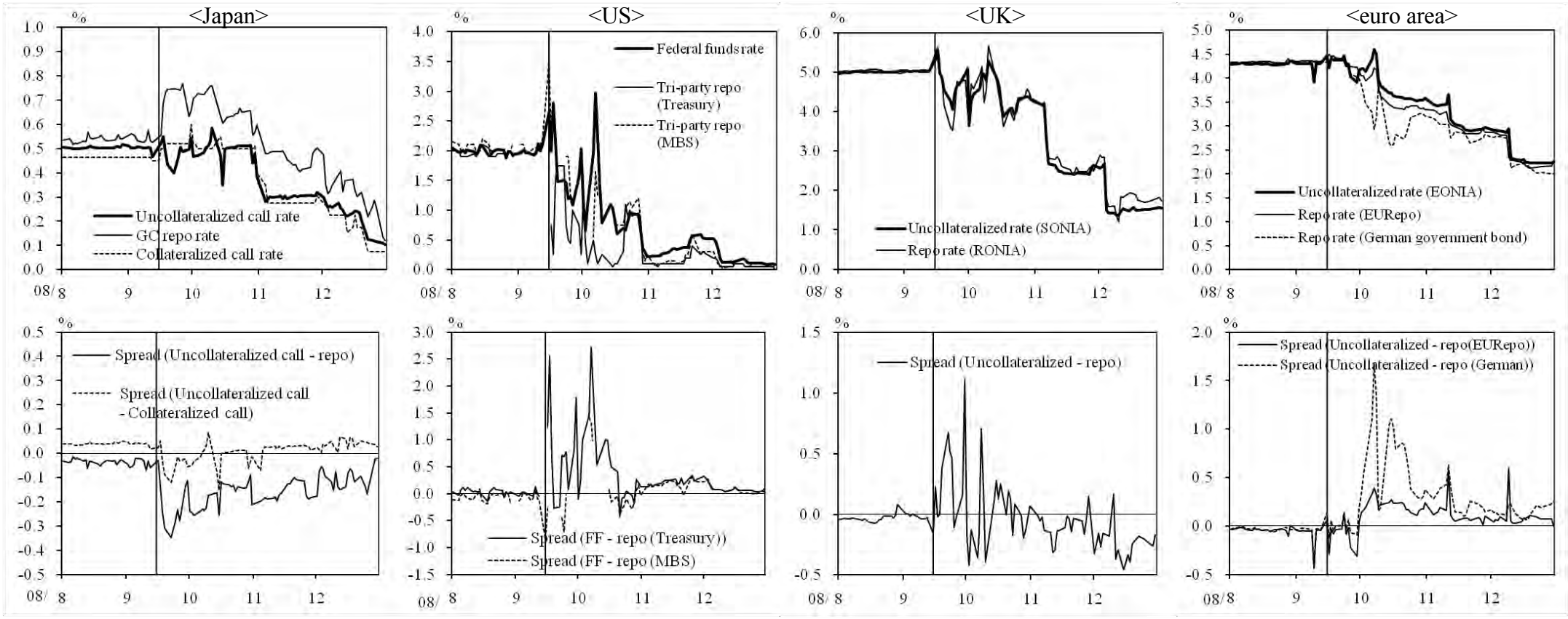
Note: CP market includes CP repurchase agreement.
Sources: Bank of Japan, Japan Securities Dealers Association, Japan Securities Depository Center.

Figure 4: Call rates and repo rate



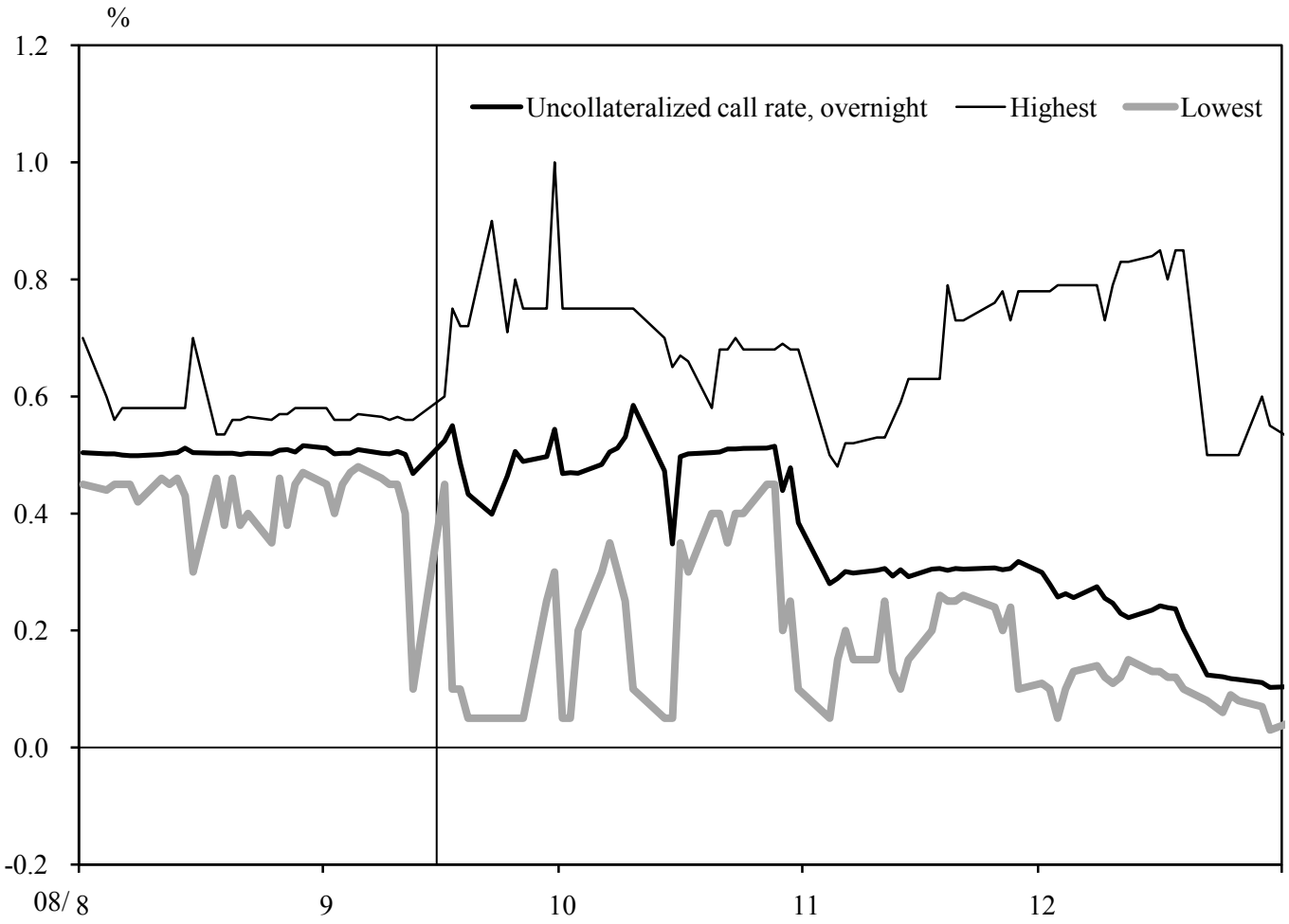
Note: The uncollateralized and collateralized call rates are T+0 overnight. The GC repo rate is T+2 overnight (spot-next) before April 23, 2012, and T+1 overnight (tomorrow-next) after that.
Sources: Bank of Japan, Japan Securities Dealers Association, Tanshi Kyokai.

Figure 5: Markets development during the crisis



Sources: Bank of Japan, Japan Securities Dealers Association, Bloomberg, Securities Industry and Financial Markets Association, Tanshi Kyokai.

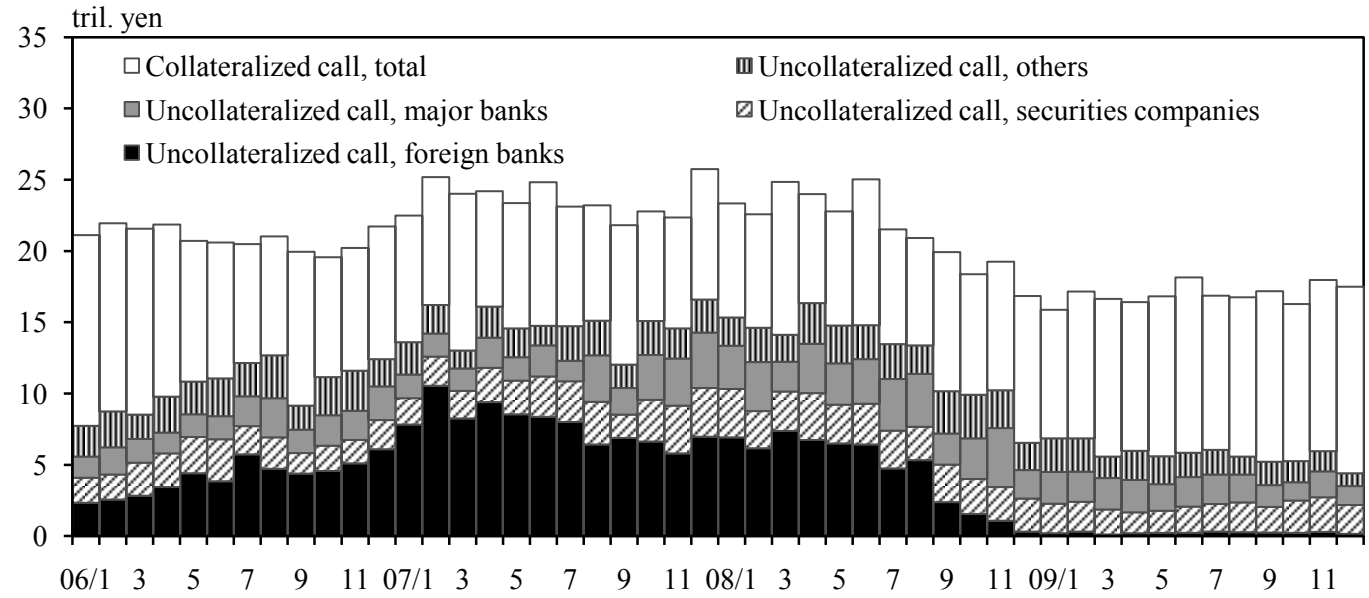
Figure 6: Uncollateralized call rate and its highest/lowest rates during the crisis



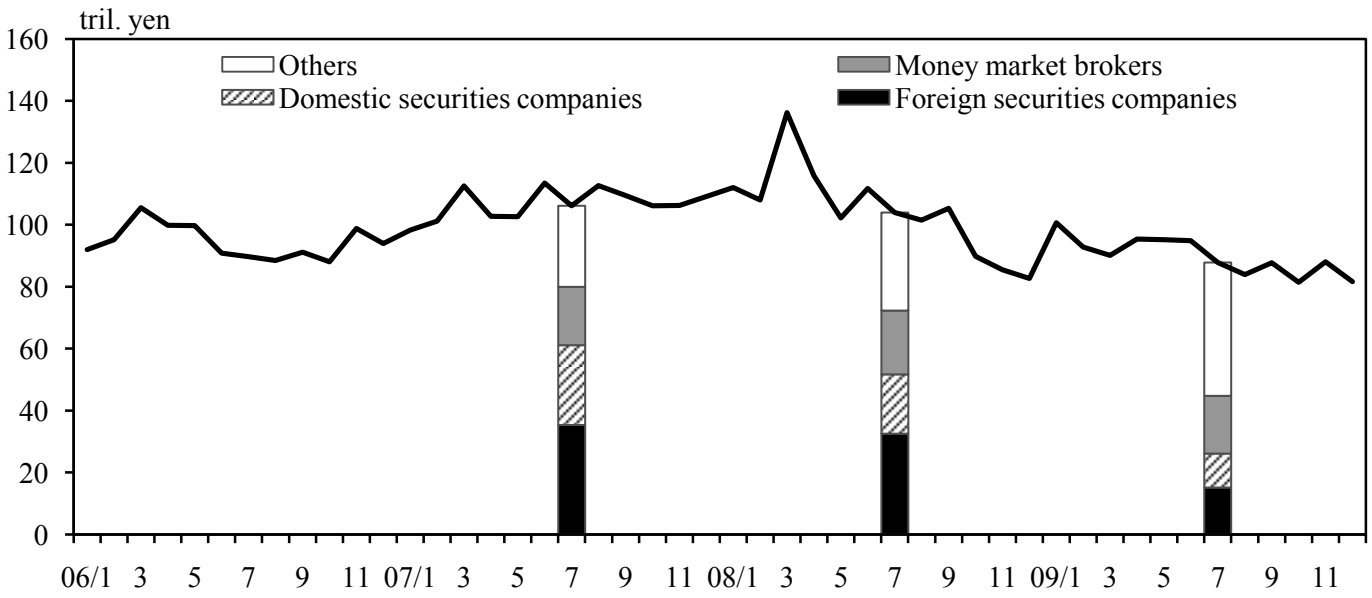
Source: Bank of Japan.

Figure 7: Participants of Call and Repo markets

(1) Call market

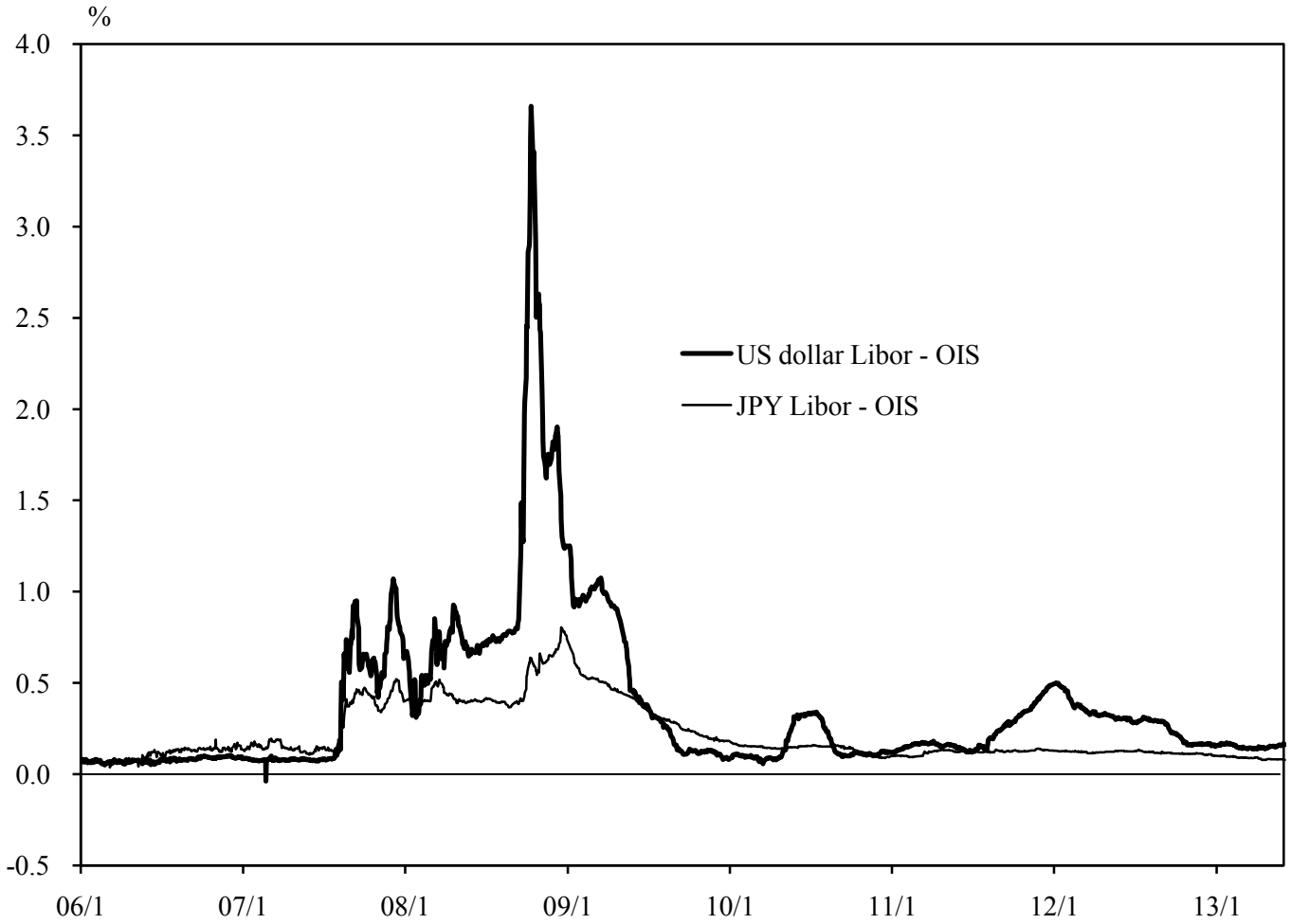


(2) Repo market



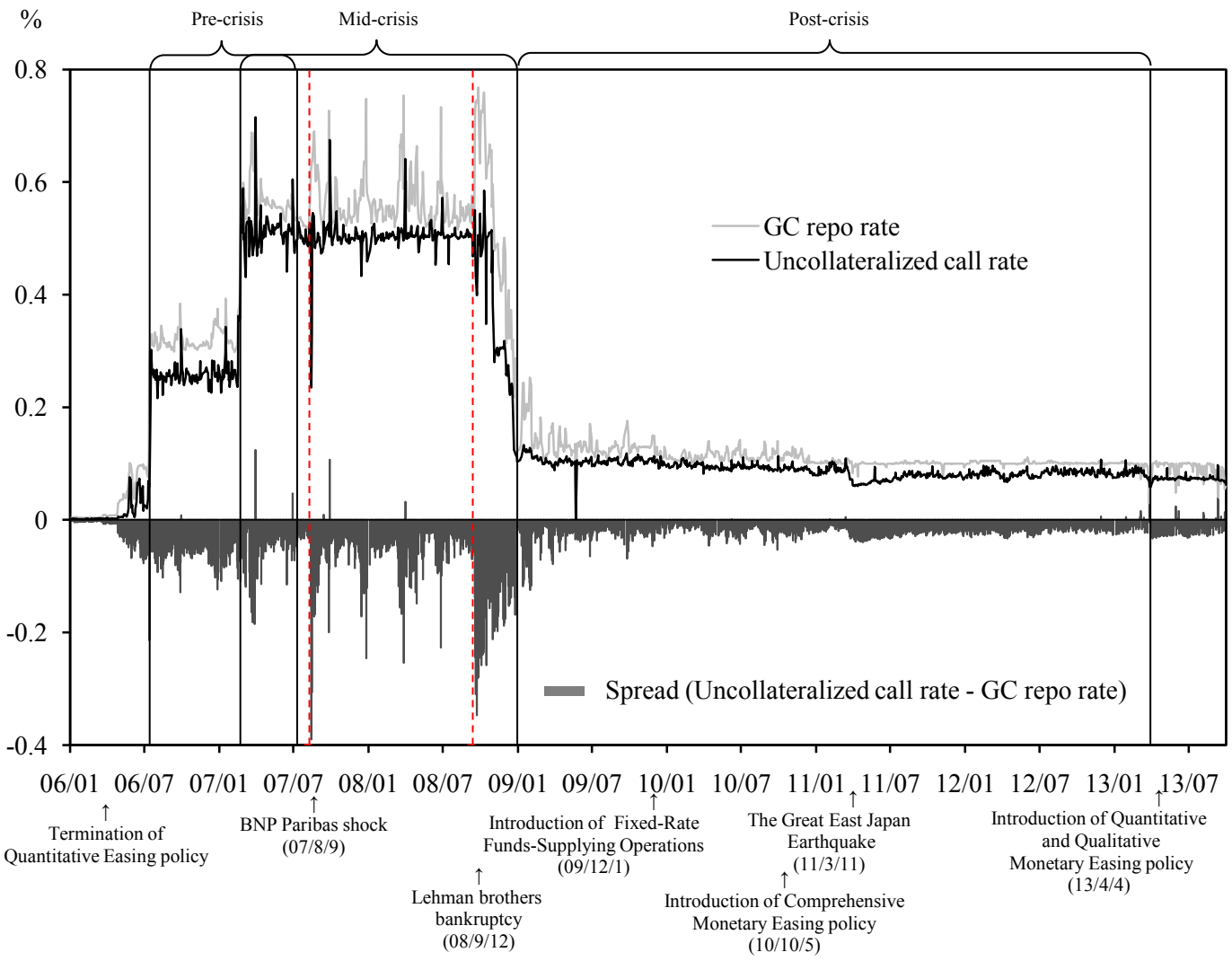
Sources: Bank of Japan, Japan Securities Dealers Association.

Figure 8: 3M Libor - OIS Spreads



Source: Bloomberg.

Figure 9: Call rate and Repo rate



Sources: Bank of Japan, Japan Securities Dealers Association.

Table 1: Repo markets in Japan, the US, the UK, and the euro area

	Japan	US			UK	euro area
			Tri-party repo	GCF repo		
Amount outstanding	122 tril. yen (Dec. 2013)	5.5 tril. dollars (May 2012)	1.6 tril. dollars (May 2012)	0.9 tril. dollars (May 2012)	0.3 tril. pound (Nov. 2013)	5 tril. euro (Dec. 2013)
Most actively traded contract period of GC repo	T+1	T+0	T+0	T+0	T+0	Mainly from T+0 to T+2 (It varies by country)
Major securities served as collateral	JGBs	Government securities, MBS, Agency securities	Government securities, MBS, Agency securities	US treasury, Agency securities	UK gilts	Government securities, corporate securities
Major participants	securities company, trust banks, major banks	primary dealer, MMF, banks, GSEs	primary dealer, MMF, banks, GSEs	primary dealer	banks, securities company, trusts	banks, securities company, trusts
Mark-to-market valuations	Yes, but less frequent	Yes	Yes	Yes	Yes	Yes
Margin call	Yes	Yes	Yes	Yes	Yes	Yes
Hair cut	Yes, but rarely observed	Yes	Yes	Yes	Yes	Yes
Fails practice	Yes	Yes	Yes	Yes	Yes	Yes

Sources: BIS, Toutan Research, Inc., Bloomberg, Securities Industry and Financial Markets Association (2014b), Japan Securities Dealers Association, Bank of England, European System of Central Banks (2013), Financial Stability Board (2012), International Capital Market Association (2014), Committee on Payment and Settlement Systems (2010), Copeland et al. (2012).

Table 2: Augmented Dickey-Fuller tests

		Pre-crisis	Mid-crisis	Post-crisis
Repo	level	-1.43	1.70	-7.17 **
	1st difference	-14.83 **	-15.69 **	-
Call	level	-1.00	-2.62	-2.99 **
	1st difference	-14.39 **	-24.29 **	-

Note: The values are ADF test statistics. ** indicates statistical significance at the 5 percent level.

Table 3: Johansen cointegration tests

Hypothesis	Pre-crisis	Mid-crisis
none	40.85 **	25.27 **
at most 1	2.35	0.51

Note: The values are trace statistics. ** indicates statistical significance at the 5 percent level.

Table 4: Pre-crisis period: 2006-2007

(1) Cointegration Vector

β_0 (intercept)	0.085	***
β_1 (slope)	0.929	***

(2) Results of estimation

	$\Delta call_t$		$\Delta repo_t$	
α (error correction)	0.083	*	-0.129	*
$\Delta call_{t-1}$	-0.075		-0.036	
$\Delta call_{t-2}$	-0.156	*	-0.049	
$\Delta call_{t-3}$	-0.093		-0.058	
$\Delta call_{t-4}$	-0.081		-0.058	*
$\Delta call_{t-5}$	-0.119	***	-0.001	
$\Delta repo_{t-1}$	0.150		0.298	**
$\Delta repo_{t-2}$	-0.146		0.079	
$\Delta repo_{t-3}$	0.132	*	0.039	
$\Delta repo_{t-4}$	0.043		0.045	
$\Delta repo_{t-5}$	-0.013		-0.026	
$\Delta bojca$ (Forecast errors)	-0.017	*	-0.002	
$\Delta spread_1$ (Yen Libor-OIS)	-0.094		0.046	
$\Delta spread_2(-1)$ (Dollar Libor-OIS)	0.139		-0.062	
$\Delta market(-1)$ (Amount outstanding of call)	-0.008		0.004	
$\Delta target(-1)$ (Policy target rate)	0.773	***	0.083	
d_3 (implementation of the Basel II)	0.009		0.021	
d_4 (the change in unit for bid rates)	0.023	**	0.003	
d_8 (monetary policy meetings)	-0.001		0.001	
d_{9c} (month-end)	0.014	***	0.005	***
d_{10c} (quarter-end)	0.071	***	0.001	
d_{11c} (year-end)	-0.061	***	-0.009	**
d_{12c} (fiscal year-end)	0.132	***	0.008	
d_{9r} (month-end)	0.006	***	0.006	***
d_{10r} (quarter-end)	-0.005		0.030	***
d_{11r} (year-end)	0.002		-0.009	
d_{12r} (fiscal year-end)	0.010		0.058	***
R^2	0.71		0.49	

(3) Variance Estimates

	$\Delta call_t$		$\Delta repo_t$
c (constant)	0.000	***	0.000
a (ARCH)	0.716		0.322
d (TARCH)	-0.021		-0.230
b (GARCH)	0.263	*	0.416

Note: Covariance is specified by Constant Conditional Correlation with ARCH, TARCH, and GARCH components. Bollerslev-Wooldridge robust standard errors are used. *** , **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

Table 5: Mid-crisis period: 2007-2008

(1) Cointegration Vector

β_0 (intercept)	0.229 ***
β_1 (slope)	0.675 ***

(2) Results of estimation

	$\Delta call_t$	$\Delta repo_t$
α (error correction)	-0.007	-0.052 **
$\Delta call_{t-1}$	-0.132 ***	0.014
$\Delta call_{t-2}$	-0.124 ***	0.024
$\Delta call_{t-3}$	-0.123 ***	-0.009
$\Delta call_{t-4}$	-0.115 ***	-0.064 **
$\Delta call_{t-5}$	-0.067 ***	-0.028
$\Delta repo_{t-1}$	0.069 **	0.098 **
$\Delta repo_{t-2}$	0.056	-0.022
$\Delta repo_{t-3}$	0.013	0.005
$\Delta repo_{t-4}$	-0.003	-0.031
$\Delta repo_{t-5}$	0.003	-0.056 *
$\Delta bojca$ (Forecast errors)	-0.013 *	0.000
$\Delta spread_1$ (Yen Libor-OIS)	-0.021	-0.073
$\Delta spread_2(-1)$ (Dollar Libor-OIS)	-0.013	0.037 *
$\Delta market(-1)$ (Amount outstanding of call)	0.008	0.000
$\Delta target(-1)$ (Policy target rate)	0.312 ***	0.267 ***
$gensaki$ (Gensaki operation)	-0.002 ***	-0.007 ***
d_5 (Repo liquidity measures; RTGS-XG, Phase 1)	-0.018	-0.132 ***
d_8 (monetary policy meetings)	-0.004	0.010 ***
d_{9c} (month-end)	0.010 ***	0.003
d_{10c} (quarter-end)	0.052 ***	0.000
d_{11c} (year-end)	-0.091 ***	0.003
d_{12c} (fiscal year-end)	0.107 ***	0.015
d_{9r} (month-end)	0.000	0.011 ***
d_{10r} (quarter-end)	-0.011 **	0.053 ***
d_{11r} (year-end)	0.008	0.054 **
d_{12r} (fiscal year-end)	0.028 ***	0.049 **
R^2	0.46	0.46

(3) Variance Estimates

	$\Delta call_t$	$\Delta repo_t$
c (constant)	0.000 ***	0.000 ***
a (ARCH)	1.929 ***	0.584 ***
d (TARCH)	-0.315	-0.556 ***
b (GARCH)	0.039	0.690 ***

Note: Covariance is specified by Constant Conditional Correlation with ARCH, TARCH, and GARCH components. Bollerslev-Wooldridge robust standard errors are used. *** , **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.

Table 6: Post-crisis period: 2009-2013

(1) Results of estimation

	$call_t$	$repo_t$
α (error correction)		
μ(Constant)	0.009 ***	0.022 ***
$call_{t-1}$	0.539 ***	0.079 ***
$call_{t-2}$	0.176 ***	-0.015
$call_{t-3}$	0.057 *	0.016
$call_{t-4}$	0.028	-0.056 *
$call_{t-5}$	0.085 ***	0.018
$repo_{t-1}$	0.083 ***	0.993 ***
$repo_{t-2}$	-0.027	-0.358 ***
$repo_{t-3}$	-0.057 **	0.060
$repo_{t-4}$	0.025	0.089
$repo_{t-5}$	-0.009	-0.004
$bojca$ (Forecast errors)	-0.001	0.000
$spread_1$ (Yen Libor-OIS)	0.007	0.010
$spread_2(-1)$ (Dollar Libor-OIS)	-0.001	0.000
$\Delta market(-1)$ (Amount outstanding of call)	0.007 **	0.001
$gensaki$ (Gensaki operation)	-0.001 **	0.000
d_1 (funds-provisioning operation with fixed rate)	-0.001	-0.002 **
$d_2(-1)$ (comprehensive monetary easing)	-0.002 ***	-0.002 ***
d_6 (RTGS-XG, Phase 2)	0.000	0.000
d_7 (shortening of the settlement cycle)	0.000	0.000
d_8 (monetary policy meetings)	0.000	0.000
d_{9c} (month-end)	0.002 ***	0.001
d_{10c} (quarter-end)	0.001	0.000
d_{11c} (year-end)	-0.004 **	0.000
d_{12c} (fiscal year-end)	-0.007 ***	-0.005 ***
d_{9r} (month-end)	0.000	0.000
d_{10r} (quarter-end)	0.000	0.001 **
d_{11r} (year-end)	0.000	0.000
d_{12r} (fiscal year-end)	0.000	-0.002 *
$d_{13}(-1)$ (Great East Japan Earthquake)	0.024 ***	0.001 *
R^2	0.88	0.86

(2) Variance Estimates

	$call_t$	$repo_t$
c (constant)	0.212 ***	0.431 ***
a (ARCH)	-0.186 ***	-0.024
d (TARCH)	0.228	0.713 ***
b (GARCH)	0.000 *	0.164 ***

Note: Covariance is specified by Constant Conditional Correlation with ARCH, TARCH, and GARCH components. Bollerslev-Wooldridge robust standard errors are used. *** , **, and * indicate statistical significance at the 1 percent, 5 percent, and 10 percent levels, respectively.