Cover Risk

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Abstract

Short covering refers to the behavior of traders to deliver a security to their short positions. Cover risk denotes the risk of short sellers being unable to deliver. As a result of the central bank large-scale asset purchases (LSAPs), borrower's bargaining power substantially weakened in the government bond market. We build a search-theoretic model to explore the impact of LSAPs by introducing the interactions between short sellers, bondholders, and a central bank. We estimate bargaining power and a variety of cover risk measures such as bond specialness, non-execution probability of repo orders, rate concession, and length of negotiation to test the model prediction using intraday data from a Japanese government bond electronic platform on specific collateral repurchase agreement (repo) transactions. We find cover risk rises as a central bank holds larger proportions of a bond. Orders to borrow bonds with greater scarcity tend to remain unfilled. The bid quote of unfilled orders is four times higher than filled orders, but still no counterparty can be found. Our results suggest that aggressive LSAPs weaken dealers' market-making capability.

Keywords: Short position; scarcity; large-scale asset purchase; search friction; repo
JEL classification: C54; E43; E52; E58; G12; G14

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1 Introduction

Short covering by dealers who make market for government bonds is either to buy the bond in the secondary market or borrow it through the repurchase agreement (repo) market. When a bond is scarce in the market, dealers sometimes cannot fill the quantity of shares required. This study focuses on such market situations in which counterparties are becoming harder to find because the large fraction of qualified owners has been reduced as a result of the aggressive large-scale asset purchase (LSAP) conducted by a central bank. Since the global financial crisis in 2008, the world's major central banks have engaged in unconventional monetary policies in the form of quantitative easing (QE) programs to stimulate their economies. These policies, however, have commonly reduced the availability of bonds from the secondary market, impairing bond market liquidity and increasing difficulty to cover short position. In fact, the number of failed transactions in the Japanese government bond (JGB) market has increased 2.58 times in the five years since 2013 and the amount of failed transactions also increased 2.59 times from ¥2.98 trillion in 2013 to ¥7.74 in 2018 according to the statistics published by the Bank of Japan (BoJ).

With regard to central bank LSAPs, D'Amico et al. (2018) quantify the scarcity value of Treasury collateral. Corradin and Maddaloni (2020) highlight the importance of security-specific demand as determinants of specialness: a premium to be paid for borrowing a specific security. They also show the occurrence of fails-to-deliver is linked to the specialness and central bank purchases in the bond market. Musto et al. (2018) show that local supply effects arising from the European Central Bank's purchasing program has had a similar impact on the frequency of failures to deliver.

Cover risk increases when it becomes more difficult to locate a counterparty who is willing to trade a particular security, or a large quantity of a given security. According to Amihud et al. (2005), this is another source of illiquidity. A short seller must negotiate the price with the counterparty in a less than perfectly competitive environment, since alternative trading partners are not immediately available. This search friction is particularly relevant in over-the-counter markets in which there is no central marketplace.

A search-based theory has been developed for the over-the-counter securities lending market by Duffie et al. (2002). Their model implies that the lending fee effects are greater for a smaller float. Vayanos and Weill (2008) extend that work to multiple-asset model to clarify the premium of on-the-run bonds. In their calibration model, borrowers' longer search times are associated with greater specialness in the repo market due to the lower competition between lenders; however, the authors do not consider scarcity. Corradin and Maddaloni (2020) extend Vayanos and Weill (2008) model introducing the central bank as the buy-hold investor and explore the cash liquidity as well as repo liquidity in the normal and crisis periods by search times. Ferdinandusse et al. (2020) show that it becomes harder for bond buyers to find sellers as the stock of bonds becomes depleted on the secondary market by the QE program.

We build a search-theoretic model based on the procedure of Vayanos and Weill (2008), specifically considering the scarcity effect on the repo market which plays a central role for short covering. We apply their procedure to explore the impact of LSAPs on the repo market. LSAPs increase the bond holding of the central bank and increase short sellers' repo demand, but they decrease the repo supply (amounts held by non–central bank investors). We predict that it increases the lender's power and forces the borrower to accept higher cost. Our order submission data allow us to distinguish between borrowers' and lenders' orders and to measure the amounts of rate concession made by borrowers and lenders separately. Larger rate concession amounts mean the weaker bargaining power. We test our prediction based on the estimates of their bargaining power. No study, as far as we know, has empirically investigated the bargaining power of repo transactions.

In addition, a central bank strengthens securities lending facility (SLF) to mitigate shortage of the bond supply. The SLF can be a last resort for short sellers to cover their position, therefore, a central bank can act as a competitor to the repo market. We introduce the interactions between short sellers, lenders, and a central bank to the search-theoretic model and solve the utility functions for the repo lending fee through Nash bargaining. Our model predicts that the lending fee will increase and short sellers will need more time to find a counterparty, given the scarcity effect of LSAPs, and ceiling effect on the repo lending fees brought about by the SLF. Our model differs from Corradin and Maddaloni (2020), in that they assume the central bank as a buyer in the cash market, whereas we consider the central bank as a lender as well.

The government bond market in Japan provides an ideal setting for examining cover risk. In our sample period, from January 2013 to April 2018, the BoJ implemented LSAP programs by targeting JGBs. The BoJ's holding of JGBs reached ¥416 trillion in March 2018, corresponding to about 85% of Japan's nominal gross domestic product, while its average holding ratio across JGBs jumped from 12.9% to 46.8%, unprecedented in the annals of central bank history. The BoJ holdings of some JGBs exceeds 85% of the outstanding debt, providing a natural experiment to determine how scarcity affects bond specialness and search frictions across bonds and maturities.

First, the scarcity effect is amplified in this period due to the large stock of bonds held by the central bank and the resulting reduction in the quantity of bonds held by private investors. This makes it more difficult for dealers to locate specific bonds in the secondary market; hence, they face greater risk in holding a short position. Since dealers rely heavily on the repo market to locate specific bonds to cover short positions, analyzing repo market transactions is the best way to identify cover risk. This study aims to measure cover risk by a variety of proxies which capture the difficulty of locating lendable securities such as the dealer's borrowing cost and search behaviors in the repo market. We also estimate non-execution risk of repo orders and how mispricing of the bid order affects the amount of rate concession as well as negotiation time in the repo market. In the search process, a trader submits a bid order with the rate assessed on the bond's scarcity and search difficulty. The trader might under- or overestimate search friction, so that the actual search time and cost depend on the initial order rate. Tick-by-tick information from the JBond Totan Securities (JBOND) repo platform allows us to compute the length of time and incremental costs of borrowing. No study, as far as we know, has empirically investigated the relation between the amount of time necessary to locate specific securities and the borrowing fees sacrificed to cover a short position. We measure the interval between the initial submission time and the time of execution or cancellation as well as the difference between the initial bid rate and the filled (or final) rate. We expect greater scarcity to be associated with higher costs, and larger degrees of underestimation (overestimation) to be associated with longer (shorter) times to execution and greater (smaller) incremental borrowing costs.

There are also cases in which an order for a bond is not filled until market closure. The unfilled repo transactions lead to greater chance of failure. We look to the order/execution results: filled, canceled, and unfilled, to investigate the scarcity effect on the short covering, which has not been investigated in earlier studies.

Second, we investigate a specific effect on days when the BoJ conducts its bond purchase operations. On those days, JGB dealers submit their offers for bonds in the BoJ's target list (eligible bonds). In case the BoJ purchases a bond they offered, they need to find the bond in the repo market. We find that nearly 50% of purchased bonds have corresponding bid orders in the repo market operated by the JBOND electronic platform after the purchase operation on the same day.[1]

Third, a central bank, such as the BoJ, starts a facility to lend the bonds it holds to dealers upon their request. Since the central bank strengthens the functional role of lending securities through its inventory, the scarcity effect and cover risk should be mitigated. Toward to the end of our sample periods, the BoJ improves SLF operation to meet dealers' needs so that the demand for lending through the SLF increases. An interesting question concerns the interaction between the rate determined in the repo market and the official lending rate of the central bank, which is lower than the usual repo rate.

In our empirical studies, we have access to all orders submitted to the JBOND market during a day, 69.1% of which are filled, 30.7% of which are canceled, and 0.2% of which are unfilled in our entire sample periods. The rate of unfilled bid (offer) orders rises (declines) as the BoJ's holding ratio increases. Besides, when comparing the filled orders with the unfilled orders at the same subperiod, the bonds with greater scarcity measured by the BoJ holding ratio tend to remain unfilled. We examine the relation between specialness and scarcity and find a positive association between them after the BoJ began aggressive QE programs. The average specialness of filled bid orders in the most recent sample period (September 2016 to April 2018) is 5.20 bps, and that of unfilled orders is 21.44 bps. The specialness of unfilled orders is four times higher than filled orders, but still no counterparty can be found. We estimate the non-execution probability of bid orders, one of the key components in cover risk, using a panel probit model conditional on bond scarcity and the order size. We show that non-execution risk rises when a bond is scarcer in the JGB market. The higher the central bank holding ratio, the greater the non-execution probability. We also estimate the determinants of the rate concession and the length of negotiation for filled, canceled, and unfilled orders.

[1] A total of 18% of the bonds purchased by the BoJ had corresponding bid orders in the repo market before the BoJ started the LSAP, which rose to 49% at the end of our sample period.

They show that bond borrowers raise initial specialness according to the scarcity level after the expansion of quantitative and qualitative easing (QQE). According to the estimated model, the final borrowing rates dropped by about 0.13–0.19 bps from the initial bid rate, and their negotiation times increased by up to 2.3 minutes as the BoJ holding ratio rose by 10%. The amount of concession and the length of negotiation increase when a bidder places an order which is underpriced. Our empirical results are consistent with the model's predictions.

Next, we conduct event studies on the central bank's purchase operation and measure its impact on borrowing rates. The BoJ reports back to dealers the results of its operation (auction) around noon, so that, if a dealer posts an offer without a position, the dealer will need to locate the bond sold to the BoJ. We can thus study whether the BoJ's purchase increases the search friction. The panel regressions indicate that the larger the amounts the central bank purchases, the greater the degree of specialness of the bid order a dealer places. The costs to cover a short position increase for the bonds purchased in the central bank operation.

We further test the impact of the SLF. In 2014, the BoJ improved the usability of its lending facility by adding a morning operation, making the facility available twice a day. The lending amount per issue was also raised in 2015 and again in 2016. After February 2016, the BoJ set the lending rate at -0.5% (or -0.6%), which is lower than the usual rate available in the repo market. If the special collateral (SC) rate drops below the BoJ's lending rate, dealers will borrow bonds from the BoJ. We thus expect the BoJ's lending facility to have a ceiling effect on the SC repo rate. In the period after September 2016, we find a ceiling effect on the bid rate. Approaching to the lending rate set by the BoJ, the amount of concession declines substantially. This means the lending rates determined by the central bank influence the fee in the repo market.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 describes the repo market and the LSAP program conducted by the BoJ. Section 4 constructs a model based on search theory and presents the research hypotheses. Section 5 describes the empirical methodology and the results. Section 6 concludes the paper.

2 Literature

The seminal work of Duffie (1996) specifies a model describing the link between the repo and cash markets and shows that bonds trading on specialness should carry a price premium in the cash market. Jordan and Jordan (1997) empirically test most of Duffie's predictions and shed light on the role played by the liquidity of bonds (on-the-run issues) and the holders of a security, introducing the concept of the availability of a specific security. Both Duffie (1996) and Jordan and Jordan (1997) use sample data from the US repo market.

Duffie et al. (2002) have developed a search-based theory for the securities lending market, extended to multiple-asset model by Vayanos and Weill (2008). Duffie et al. (2002) study the over-the-counter market and construct a dynamic model for the determination of prices, lending fees, and short interest (the quantity of securities held short). Their model implies that lending fee effects are larger for a smaller float. The expected price decline associated with lending fees is then likely to be more pronounced in situations characterized by a high degree of belief heterogeneity and a small number of circulating shares. In the calibration model proposed by Vayanos and Weill (2008), borrowers' longer search times are associated with greater specialness in the repo market, due to the lower competition between lenders. The authors aim to clarify the premium of on-the-run bond, but do not consider scarcity. Corradin and Maddaloni (2020), whose paper is one of the closest to ours, extend Vayanos and Weill (2008) model introducing the central bank as a buy-hold investor and explore the impact of the central bank's purchases on the scarcity premia in the repo market during the sovereign debt crisis. Corradin and Maddaloni (2020) and ours are similar in addressing the case in which the demand for repo transactions is high because of the purchase operations of the central bank and in which collateral bonds have become scarce in the market due to the LSAPs based on the search theoretic model, though, unlike their setting, in our model the central bank acts not only as a buy-hold investor but also as a lender through its lending facility.

Duffie et al. (2005) build a dynamic asset-pricing model that captures search and bargaining features and analytically derive equilibrium allocations, prices negotiated between investors, as well as market makers' bid and ask prices. Duffie et al. (2007) show that illiquidity discounts are higher when counterparties are harder to find or the fraction of qualified owners is smaller. Ferdinandusse et al. (2020), whose paper is also close to ours, model sovereign bond markets in a search-theoretic framework based on that of Duffie et al. (2005). They show that, as the stock of bonds becomes depleted on the secondary market by the QE program, it becomes harder for buyers to find a seller. The authors predict that the QE program crowds out buyers besides the central bank and leads to lower bond liquidity. We apply their procedure to construct a model exploring the impact of LSAPs on the JGB repo market by introducing the interactions between short sellers, lenders, and a central bank.

There are many empirical works on the impacts of the QE programs on the repo market. Among them, D'Amico et al. (2018) quantify the scarcity value of Treasury collateral by estimating the impact of security-specific demand and supply factors on the repo rates of all outstanding US Treasury securities. This scarcity effect seems to pass through to Treasury cash market prices, providing additional evidence of the scarcity channel of QE. The US Federal Reserve System's reverse repo operations could help reduce scarcity premiums by alleviating potential shortages of high-quality collateral.

Both Corradin and Maddaloni (2020) and Musto et al. (2018) are related to our empirical approach in terms of investigating the link between short-selling activities and specialness. Corradin and Maddaloni (2020) highlight the importance of security-specific demand and introduce a novel measure of availability on the street by using the amount of a security that is available for trading, possibly linked to short-selling activity. The authors analyze the determinants of the quantiles of the distribution of specialness by means of quantile panel regressions, and they show that very special bonds are more sensitive to sizable changes in supply and demand. They also find the probability of a fail-to-deliver increases with the specialness of the bond. Kinugasa and Nagano (2017) examine the impact of the BoJ's QQE on repo specialness, using repo transaction data from May 2014 to March 2017. They show that the BoJ's holding ratio of JGBs increases repo specialness, and the BoJ's SLF mitigates bond scarcity.

Musto et al. (2018) show that a decline in the frequency of special trades is associated with an increase in the volume of failures. Local supply effects arising from the European Central Bank's Securities Markets Programme purchases also had a similar impact, but they were mitigated by the introduction of penalties for failure to deliver. Dunne et al. (2011) analyze how the crisis affected the bidding behavior of banks in refinancing operations in the euro area. Mancini et al. (2016) conduct a comprehensive study of the European repo market and show that the importance of the central counterparty-based segment in this market makes it more resilient during crises and even acts as a shock absorber.

Boissel et al. (2017) argue that central clearing counterparties provide some protection in periods of intermediate sovereign stress (2009–2010), but this protection became ineffective at the peak of the sovereign crisis (in 2011). Buraschi and Menini (2002) analyze more specifically the relation between the current term structure of special repos and future collateral values, using data on the German government repo market. Skinner and Dufour (2006) analyze the Italian BTP repo market. Arrata et al. (2018) show that most short-term interest rates in the euro area are below the European Central Bank deposit facility rate, the rate at which the central bank remunerates banks for excess reserves. Using proprietary data from a public sector purchase program's purchases and repo transactions for specific (special) securities, the authors assess the scarcity channel of the public sector purchase program and its impact on repo rates.

The SLF run by the central bank has a competitive and complementary relationship with the repo market. Fleming et al. (2010) assess the effectiveness of the term SLF of the central bank and find that it significantly narrowed repo spreads between Treasury collateral and less liquid collateral. The authors find that the effects are driven by operations in which appreciably less liquid securities can be pledged as collateral and that such operations increase the repo rates for liquid non-Treasury collateral. We build a model considering the effects of SLFs on short sellers' behaviors.

3 Repo transactions and LSAPs in Japan

In this section, we first describe the role of repo transactions in the JGB market and summarize recent LSAP programs in Japan, which increased scarcity. We next explain the central bank's SLF, which has a competitive relationship with repo transaction.

3.1 Role of the repo market

A repo is a form of short-term (usually overnight) borrowing or lending in government securities. In a repo transaction, a lender turns over an asset to a borrower in exchange for cash. At maturity, the borrower returns the asset and the lender returns the cash, together with some previously agreed interest rate payment, called the repo rate. A repo transaction is categorized as either a general collateral (GC) repo or an SC repo. GC repo transactions cannot specify bonds to be traded mainly for the purpose of raising funds, and their rates are generally priced at a level close to the risk-free interest rate. On the other hand, SC repos are bond-specific transactions for the purpose of lending those bonds, and their rates are priced below the GC repo rates, according to bond availability.

The cash and repo markets are closely linked through short sales. The repo market is often used when a dealer creates short-selling positions in the cash market. The most typical way is to sell a bond short in the cash market while simultaneously borrowing the same bond through an SC repo in order to cover a short position. Thus the specialness, measured by the difference between the GC and SC rates, indicates information on the state of short-selling pressures in the cash market. Many studies, such as Duffie's (1996), show that specialness increases with the amount of short-selling activity in the cash market and is driven by the demand for short positions, constraints on the available supply, and the liquidity of the security.

The reduction in available bonds increases the possibility of dealers being unable to close their short positions in the JGB cash market (Pelizzon et al. (2018)). Under market conditions with scarce bonds, the demand for procuring bonds in the repo market increases. The reduction in available bonds in the cash market is equivalent to the reduction of collateral for the repo market. The reduction of collateral increases the difficulty of borrowing the bonds. Therefore, the SC rate of a scarce bond should be at a lower level and its degree of specialness should be higher (e.g., Corradin and Maddaloni (2020), D'Amico et al. (2018), Arrata et al. (2018), Brand et al. (2019)). We next describe increasing scarcity in the JGB market.

3.2 Summary of recent purchase programs

During our sample period, the amount traded in the JGB repo market is increasing, which is partly attributed to increases in the BoJ's JGB holdings and transactions by foreign investors and. Purchase operations by a central bank have two different effects on the repo market: one is to increase the demand for repo transactions to cover short positions created in response to the central bank's purchase operations, and the other is to reduce the supply of repo collateral generated by the central bank's cumulative purchases. Both effects push specialness.

Our sample period is from January 2013 to April 2018, due to the availability of the repo transaction data. A purchase program had already begun in 2013, but, on April 4, 2013, the BoJ announced the introduction of QQE, which increased its purchases of JGBs to an annual amount of about ¥50 trillion.[2] On October 31, 2014, the BoJ announced the expansion of the QQE such that the purchase amount would increase at an annual pace of about ¥80 trillion, approximately ¥30 trillion more than the previous amount, thus aiming to decrease interest rates across the entire yield curve and to shift its purchases further toward longer-term bonds. On January 29, 2016, the BoJ introduced QQE with a negative interest rate and revealed a policy of targeting negative interest rates and of continuing to purchase JGBs in amounts

[2] $1 is roughly equivalent to ¥110

increasing by about ¥80 trillion annually. On September 21, 2016, the BoJ introduced QQE with yield curve control and announced its intent to purchase JGBs to maintain the 10-year JGB yield around 0%. The BoJ also announced the introduction of a new purchase operation tool: purchases of JGBs with yields designated by the BoJ (fixed-rate purchase operations).

Figure 1 shows the amounts (in trillions of yen) of nominal JGBs purchased by the BoJ and its holding ratio (%).

[Figure 1 about here.]

As shown in Figure 1, the BoJ gradually increased its holdings of JGBs before 2013, but accelerated its pace of bond purchases after the QQE announcement in April 2013. The monthly purchase amounts in the first QQE period (QQE-I) are approximately double the previous ones. After expansion of the QQE, in the second QQE period (QQE-II), the monthly purchase amounts increased and held at that level until the period of QQE with a negative interest rate (NI). After introducing yield curve control (YCC-I) on September 2016, the BoJ's purchase amounts decreased slightly. On the other hand, its holding ratio sharply increased after the introduction of QQE. Although the growth rate slowed according to the decline in purchases, the BoJ's holding ratio continued to increase and reached around 47% at the end of our sample period.[3]

As explained above, the BoJ accelerated its LSAPs several times during our sample period. According to the BoJ's LSAP program history, we define five subperiods, as follows:

CE-0	1-Jan-2013∼	Comprehensive easing
QQE-I	4-Apr-2013∼	First QQE (purchased ¥50 trillion of JGBs per year)
QQE-II	31-Oct-2014∼	Second QQE (purchased ¥80 trillion of JGBs per year)
NI	29-Jan-2016∼	QQE with negative interest (kept purchase amount)
YCC-I	21-Sep-2016∼	QQE with yield curve control (declined purchase amount)

We set the end of the YCC-I period to be April 2018. On May 1, 2018, the JGB settlement cycle was shortened from two business days (T+2) to one business day (T+1). Although this shortening brought about interesting changes to the repo market, these are beyond the theme of this paper, so we use the sample up until this system change.

3.3 Central bank lending facility

The BoJ's SLF started as early as 2004 in order to mitigate tightness of JGB supply. It functions as follow: most SC repo transactions in the repo market are in the T+2 clearing cycle until April 2018. The BoJ lends the bonds from its holdings on the day following the repo transaction. A dealer who wants to cover a short position and cannot find a counterparty in the repo market can therefore cover it by borrowing the bond from the BoJ the following day, although the cost is mostly higher than in the repo market.

[3] We exclude Treasury discount bills, floating-rate bonds, and inflation-indexed bonds. Our data consist of nominal two-, five-, 10-, 20-, 30-, and 40-year JGBs.

The BoJ changed its lending requirements to ease the deterioration in liquidity caused by its LSAPs. In 2014, lending facility offers were added in the morning and thus become available twice a day. The lending amount per issue was also raised in 2015 and in 2016. After February 2016, the BoJ clarified the upper limit lending rate to be the uncollateralized overnight call rate rounded off to the first decimal place minus 0.5%. Since the overnight call rate ranged between 0% and −0.1%, the upper limits of the lending rates were set to be −0.5% or −0.6%. This central bank lending rate may set a lower limit on the SC repo rate (upper limit of specialness). If the SC rate is currently lower than −0.5% (or −0.6%) in the repo market, dealers will reasonably choose to forgo borrowing bonds in the repo market and, instead, borrow from the central bank the next day. We test the ceiling effect of the central bank's lending facility on the SC repo rate in Section 5.2.7.

4 Model and empirical hypotheses

In this section, we propose a model based on the search-theoretic model introduced to the over-the-counter bond market by Duffie et al. (2002). We then describe our model prediction and the hypotheses to be examined in our empirical analyses.

4.1 Search-theoretic model

We construct a model based on a search-theoretic model. We refer to the models of Vayanos and Weill (2008) and Ferdinandusse et al. (2020) to clarify the impact of increasing central bank holdings on the repo market.

We consider an infinite-horizon, steady-state economy. We assume three types of investors in the bond lending market: short sellers, lenders, and a central bank. Short sellers, whose measure is α_{ss}, gain profits by purchasing bonds at low prices and selling them at high prices.[4] They hold a transaction asset of value one for which they agree to sell one bond to the central bank or other investors. Since they do not hold the bond at the time they decide to sell, they try to borrow the bond either in the repo market or through the securities lending facility (SLF) run by the central bank. The lenders, whose measure is α_l, are non-central bank bondholders. They hold a bond at quantity of one and do not sell their bonds, making a profit by lending their bonds in the repo market. The ratio $\frac{\alpha_{ss}}{\alpha_l}$ is the ratio of supply to demand in the repo market and represents the tightness of the repo market. The higher the ratio, the harder it is to find a counterparty in the repo market. We now introduce the central bank not only as a bond holder but also as a lender, which is not included in the previous work. The central bank holds the bonds it purchases to maturity and lends them through the SLF. As already mentioned, since the central bank's SLF is implemented the day following the repo transaction and its rate is set lower than the SC repo rate in most cases, short sellers borrow

[4]Although not all borrowers are short sellers, for the sake of simplicity, no other borrowers appear in the model. The utility functions of borrowers besides the short sellers involve the case in which both h_s and h_f are zero in Eqs. (2) to (3).

bonds through the SLF only when they can't find a repo counterparty with a better rate than that through the SLF. Figure 2 shows the flows in the bond lending market.

[Figure 2 about here.]

We assume that, in steady state, the lifetime utility of a lender or a short seller is the present value of their expected utility flows, net of payments for asset transactions, discounted at a rate $r > 0$. We define V_l, V_{ss}^{repo}, and V_{ss}^{cb} as the utilities of lenders, borrowers (short sellers) in the repo market, and borrowers (short sellers) through the SLF, respectively.

We assume lenders need to pay a small holding cost e_l in each period. We also assume that the probability of finding a counterparty depends on the number of such counterparties on the market. A lender finds a borrower (short seller) with probability $\lambda\alpha_{ss}$ and obtains ω for the bond in a successful repo transaction. Note that λ is the Poisson arrival intensity, and lenders and short sellers are matched with intensity λ. That is, given a group of short sellers with mass α_{ss}, a particular lender meets a short seller with probability $\lambda\alpha_{ss}$. In our model, a borrower pays a positive lending fee ω to the lender. Specialness is calculated by dividing ω by the bond price, and the implied SC rate is the difference between the risk-free rate r and the specialness. If a lender cannot find a counterparty in the repo market, the lender will not make a profit and will need to pay the holding cost in the period. The lenders' utility V_l is thus

$$V_l = \frac{1}{1+r}\left(-e_l + \lambda\alpha_{ss}\omega + (1-\lambda\alpha_{ss})V_l\right). \tag{1}$$

We next consider the utility of short sellers. First, we define the profits of short sellers in the bond spot market. A short seller makes a profit by purchasing bonds at low prices and selling them at higher prices in the JGB spot market. We define h_s as the profit arising from the sales and purchases of a bond. Second, we define the borrowing cost. A short seller will first try to borrow the bond to be sold in the repo market, rather than borrowing from the central bank. That is because repo transactions are conducted the day before the BoJ's lending through the SLF, and the SC repo rate is more favorable, in most cases, than the central bank's lending rate for short sellers. The short seller finds a lender in the repo market with probability $\lambda\alpha_l$ and has a cost ω for the borrowing fee when the repo transaction succeeds, and then exits the repo market. λ is the same Poisson intensity as in Eq. (1). When a short seller cannot find a lender in the repo market (with probability $(1-\lambda\alpha_l)$), the short seller will then try to borrow the bond from the central bank. Thus, the short seller's utility in the repo market is in Eq. (2).

$$V_{ss}^{repo} = \frac{1}{1+r}\left(\lambda\alpha_l(h_s-\omega) + (1-\lambda\alpha_l)V_{ss}^{cb}\right) \tag{2}$$

Lastly, we consider the expected utility of the case where short sellers could not cover their short in the repo market. We define δ as the probability that the short seller will be successful attempting to borrow through the central bank's SLF. The term δ is assumed to remain constant for the LSAPs, because a central bank will try to respond to investors' demand for bond lending to maintain the liquidity of the JGB market, which tends to decline due to

LSAPs. Let the central bank's lending fee be sl, which is set much higher than ω. When a short seller can borrow the bond through the SLF, the short seller exits the bond lending market and the short seller's profit is the difference between the profit h_s and the borrowing cost sl. We also consider the case in which a short seller cannot borrow in the repo market or from a central bank. If the short seller does not hold the bond on the sale date, the short seller will fail the transaction. Let $h_f(> 0)$ be the cost of failure, which includes penalties such as a decline in the short seller's credit. Considering these cases together, we find that the utility of short sellers who intend to borrow through the SLF is in Eq. (3):

$$V_{ss}^{cb} = \frac{1}{1+r}\left(\delta(h_s - sl) - (1-\delta)h_f\right) \tag{3}$$

We now determine the lending fee by introducing bargaining power. When a short seller finds a lender in the repo market, they bilaterally bargain over the lending fee. We assume the lending fee is determined through Nash bargaining, which is applied by Duffie et al. (2005) and Ferdinandusse et al. (2020), among others. Under this assumption, the lending fee ω must lie between the utilities of the marginal lender and the marginal borrower (short seller) in the repo market, that is,

$$\omega = \phi V_l + (1-\phi)\left(h_s - V_{ss}^{repo}\right) \tag{4}$$

for some $\phi \in [0,\ 1]$, where ϕ measures the short sellers' bargaining power.

We then solve the lending fees with Eqs. (1) to (4):

$$\begin{aligned} \omega \;=\; & h_s - \frac{\phi(1+r)(e_l + rh_s)}{G(r,\phi,\lambda,\alpha_l,\alpha_{ss})} \\ & + \frac{(h_f - \delta h_f - \delta h_s + \delta sl)(1-\phi)(1-\lambda\alpha_l)(r+\lambda\alpha_{ss})}{(1+r)G(r,\phi,\lambda,\alpha_l,\alpha_{ss})} \end{aligned} \tag{5}$$

where

$$G(r,\phi,\lambda,\alpha_l,\alpha_{ss}) = r + r^2 - (1-\phi)(r\lambda\alpha_l - \lambda\alpha_{ss} - r\lambda\alpha_{ss} + \lambda^2\alpha_l\alpha_{ss}) \tag{6}$$

4.2 Search-theoretic model and the impact of LSAPs

We now consider the impact of the LSAPs on the bond lending market based on our model. After the introduction of QQE, the BoJ purchased large amounts of government bonds. The number of short sellers increases because of the high demand for short selling in response to the central bank's purchase operations. Thus, the measure of short sellers, α_{ss}, increases after the introduction of the QQE. On the other hand, the increasing scarcity of the JGB market due to the BoJ's LSAPs diminishes the number of lenders, and the measure α_l decreases.

We explore the impact on cover risk and the borrowing fee resulting from the changes in the measures of short sellers, lenders. First we explore the impact on search times in the repo market resulting from the LSAPs.

Proposition 1 *A lender will take less time and a short seller will take more time to execute an order as the central bank's holdings increase.*

Proof. Since λ is the Poisson arrival intensity and a particular lender will meet a short seller with probability $\lambda\alpha_{ss}$ in our model, $\frac{1}{\lambda\alpha_{ss}}$ reflects the lender's search time to find a counterparty. Thus, under the assumption of our model, the lender's elapsed time decreases as α_{ss} increases, depending on the central bank's purchase operations. On the other hand, $\frac{1}{\lambda\alpha_l}$ reflects the search time for a short seller seeking a counterparty, given a group of lenders with mass α_l. A short seller takes more time as α_l decreases according to the central bank's increase in holdings.

We next consider the effect of LSAPs on the lending fee. Since Eq. (5) has a complicated structure and it is difficult to investigate the effects of changes in the numbers of lenders and short sellers, we perform a calibration exercise. Figure 3 plots the lending fee ω as a function of the measure of lenders, α_l, or short sellers, α_{ss}. We set the parameter values as listed below Figure 3 and examine the dependence of ω on α_l or α_{ss}. We find that the lending fee rises as α_l decreases or α_{ss} increases. The decrease in the number of lenders resulting from the increase in the central bank's holdings leads to higher lending fees. The increase in the number of short sellers due to the demand from each purchase operation also leads to higher lending fees. We thus propose the following prediction, based on our search-theoretic model:

Proposition 2 *The lending fee increases with the central bank's LSAPs.*

[Figure 3 about here.]

4.3 Hypotheses

In this section, we describe the research questions to be tested in the empirical analyses.

In Duffie's (1996) model, specialness—the premium for procuring a specific security in the repo market—is driven by the demand for short positions, constraints on the available supply, and the liquidity of the security. As D'Amico et al. (2018), Corradin and Maddaloni (2020) and many other empirical studies have shown, in the SC repo market, collateralized transactions are security specific, and the scarcity of the underlying collateral should be the main determinant of the SC repo rate (or specialness). Our search-theoretic model described in Sections 4.1 and 4.2 predicts that the lending fee will increase with a decrease in the measure of lenders, and an increase in the measure of short sellers and that, when we compare two individual bonds, the SC rate of the bond with tighter supply–demand balance will be lower (specialness will be higher). This means that the cover risk of this specific bond is higher. We test the following hypothesis for the scarcity effect on repo specialness.

Hypothesis 1 *The greater the scarcity, the larger the GC–SC spread in the repo market.*

Cover risk has two aspects: the amount of time and associated incremental costs to locate a specific bond. In the calibration model proposed by Vayanos and Weill (2008), which does not consider scarcity, longer search times for borrowers are associated with greater specialness in the repo market due to the lower competition between lenders. Even though few collateral bonds are available for lending, the central bank repeats the purchase operations in the form of an auction. If the auction bidder does not hold the bond to be sold, he will consider borrowing the bond in the repo market. As described in Section 4.2, a lender will take less time and a short seller will take more time to execute an order as the central bank's holdings increase. Based on this argument, the elapsed time from the bid (offer) order placement until execution is expected to be longer (shorter) as the central bank's holdings increase, and we propose the following hypothesis.

Hypothesis 2 *The greater the scarcity, the longer (shorter) a bid (offer) order to be filled.*

We further consider the effect of the scarcity on the bargaining power. Our search model assumes that if a repo transaction occurs, the lending fee is set so that the lender receives a fraction $\phi \in [0,\ 1]$ and the borrower (short seller) receivers $1 - \phi$ of the total surplus. The greater scarcity brought by the central bank' bond purchases is expected to increase (decrease) the bargaining power of lenders (borrowers) in the repo market. Our calibration exercise in the top panel of Figure 4 shows that the lending fee, ω, is higher for weak borrowers' bargaining power, and lower for stronger borrowers' bargaining power. We thus propose the following hypothesis:

Hypothesis 3 *The bargaining power of lenders gets stronger with the central bank's LSAPs.*

No study, as far as we know, has empirically investigated the bargaining power of borrower and lenders in the repo transactions. Our order submission data enables us to keep track rate changes of bid and offer orders. We can measure the rate concession amounts of the lender and the borrower separately. Larger rate concession amounts mean the weaker bargaining power. In the empirical analysis in Section 5.2.4, we test whether borrowers or lenders are forced greater concession which is our proxy of bargaining power.

[Figure 4 about here.]

We next consider the effects of the central bank's purchase and lending operations. In the case of a scarce bond, demand for repo transactions must increase as a result of the central bank's purchase operations. An increase in short sellers will tighten the demand–supply situation, making it harder to find counterparties. This tightness of the demand–supply factor decreases the SC rate (increases specialness) according to our search and bargaining model.

Hypothesis 4 *A central bank's purchase operation increases the GC–SC spread of the purchased bond due to increased search frictions for dealers.*

The SLF operated by the central bank can mitigate a tight demand–supply situation. It provides the alternatives for short sellers covering their short positions. However, the lending rate through the SLF is set above the normal rate obtainable in the repo market, so that it works as a last resort to avoid short seller failure. The bottom panel of Figure 4 illustrates the repo lending fees for three different SLF lending fees. We find for example, when the SLF fee is 0.005 (purple thick line), the repo lending fee doesn't exceed 0.005. Based on the model, we expect that the SLF rate creates a ceiling effect on the SC repo rate. We thus test the following hypothesis for the effect of the SLF on the repo market.

Hypothesis 5 *The central bank's SLF has a ceiling effect on the SC repo rate.*

Since after February 2016 the BoJ lending rate is at the level of −50 basis points (bps)—or −60 bps—we examine the ceiling effect of the SLF on the SC rate by testing whether the SC repo rate reaches that level.

5 Empirical analysis

5.1 Data and variables for empirical analysis

5.1.1 Data

Our order submission data set, which includes the date, time, bond code, order number, rate, and volume, is obtained from the electronic platform provided by JBOND. The data allows us to keep track initial rate and filled rate for individual bid/offer orders. For the empirical analyses, we use overnight SC repo transactions that are settled two business days after the transaction date, that is, 99.0% of all the transactions in our sample.

The GC–SC spread is defined as the difference between the GC and SC repo rates for a specific security, repo maturity, and trading day. We calculate the GC–SC spread on a daily basis—and not a deal basis—to prevent the effects of specific bonds with high numbers of transactions from becoming too strong except for the deal basis analysis in Section 5.2.3. The daily SC repo rates for a security are calculated by the volume-weighted average of the bond over all the transaction data of the security that day. We use the Tokyo Repo Rates of the next trading day's SC transactions as our GC repo rates.[5] Our data cover the period from January 4, 2013, to April 30, 2018.

Figure 5 shows the time-series evolution of the GC–SC spread, averaging over all securities being traded in the repo market. We can see many spikes in the daily average GC–SC spread. Some of these are at the end of a quarter, as well as at the end of a month, caused by strong demand from financial institutions. The sizes of the spikes increase at the end of QQE-I, and the GC–SC spread remains volatile until YCC-I. The average level of the GC–SC spread rises after NI. Changes in the GC–SC spread are reflected by scarcity, maturity-specific demand, and calendar effects, such as at the end of a quarter.

[Figure 5 about here.]

[5]The Tokyo Repo Rate is calculated as the average of the rates of the reference institutions. Since the purchase date of an SC repo is two days after the transaction but that of a GC repo (Tokyo Repo Rate) is the next trading day, we use the Tokyo Repo Rate of the next trading day of the SC transaction to calculate the GC–SC spread based on the same repo purchase date.

In our empirical analyses in Section 5, we further restrict our sample. Some bonds, such as those that were recently issued and or the cheapest to deliver, are actively traded, whereas others are rarely traded in the repo market. The rates of inactive bonds can lead to outliers, so we only use securities that are traded in more than half of the days in each subsample period. Of the approximately 307.5 bonds traded during each sample period, on average, 134.5 bonds meet the criteria when we average over the five subperiods. This represents about 44% of the eligible securities for trade. On a volume basis, highly liquid securities comprise approximately ¥2.2 trillion a day during the sample period, whereas the remaining securities comprise approximately ¥0.7 trillion, indicating that our sample represents about 76% of all JBOND SC repo transactions, by amounts.

Repo transactions are not very active in the morning session (7:30 a.m. to 11:00 a.m.), and the proportion of orders in the morning session is 10.9% during our sample period. We find that the SC rates in the morning session sometimes differ from those in the afternoon session.[6] Additionally, the way to handle the lunch break is an annoying problem when we calculate the elapsed time between a new order entry and execution, as described below.[7] We thus exclude orders placed in the morning session and use orders placed in the repo market after 12:20 p.m. for our sample. We further exclude orders with SC rates higher than GC rates, because they include orders with abnormal rates that may cause mistakes.

To investigate the cover risk that short position dealers carry in the JGB market, in Section 5, we use the GC–SC spread at the time of placing a new order. When a bond is scarce in the market, its GC–SC spread should be wider at the time of order placement. We analyze the GC–SC spread of bid and offer orders separately, given the fact that dealers submit a bid order to cover short positions and submit an offer order to lend cash. Bids and offers thus have different motivations, which is why we distinguish bids from offers.

In addition to the GC–SC spread at the time of order placement, we propose two more measures to determine cover risk in the repo market. When a trader places a new order, we can track the order to execution, cancellation, or modification with the order ID. There are three possibilities for the order/execution results: filled, canceled, and not executed before market close (unfilled).

To investigate cover risk, we measure delays in order execution and the incremental execution costs for all the orders. We track each order's execution, cancellation, or modification by the order ID and calculate the time and rate change between a new order placement and its execution. As far as we know, we are the first to investigate search friction by tracking the search costs of individual repo orders. We examine the search times and changes for filled, canceled, and unfilled orders separately. When calculating the search times and rate concession, we again distinguish between orders initiated as a bid or as an offer. Bid orders include cases in which bidders must cover their short positions, whereas offer orders are aimed at raising money using bonds in hand. We present the statistics of the variables for bid and

[6]Repo transactions in the morning session became active after the clearing cycle was shortened in May 2018.

[7]Only cancellations can be made during the lunch break on the JBOND repo system.

offer orders separately and then show the determinants of rate concession and elapsed time for bid orders in Section 5.2.5. We focus on bid orders in the aim of revealing the impact of the BoJ's LSAPs on short-selling activities in the repo market.

We further investigate the impact of the central bank's purchase operations and lending facilities on search costs. In the case of bonds purchased by a central bank operation today, the dealer needs to cover a short position in the repo market. We separate repo orders into bonds purchased by the BoJ and others and test the impact of each purchase operation on the repo market in Section 5.2.6. We also test in Section 5.2.7 whether the central bank's lending facility sets a lower limit on the SC repo rate, analyzing the rate concession from the initial ordered SC rate.

5.1.2 Variables for the empirical analyses

We investigate the impact of bond scarcity on repo specialness using a panel regression method. As seen in Figure 1, the BoJ's LSAPs have a significant impact on the bond supply. The BoJ's holding ratio of nominal JGBs was around 10% until mid-2012 but then increased sharply and reached around 47% in April 2018. The reduction in available bonds increases the likelihood that dealers will be unable to close their short position in the JGB cash market. The SC rate (price) of a bond that is scarce in the market should be lower (higher) and the specialness should be greater. We construct our scarcity variable as the BoJ's security holdings n on day t as a percentage of its amount outstanding, $holding_{n,t}$. This variable indicates whether sufficient bonds exist in the market. To control the outstanding amount of a bond, we also define $outstanding_{n,t}$ as the logarithm of the outstanding amount of security n on day t.

In each purchase operation, the BoJ announces the target securities. The BoJ's purchase decrease the float of bonds in the secondary market. After years of operation, market liquidity conditions decrease further and further, such that the demand for procuring bonds in the repo market and repo specialness increase. To examine the effect of being purchased by the BoJ, we define $purchase_{n,t}$ as the logarithmic amount of the targeted security n purchased in day t's operation.[8]

The difficulty of execution differs, depending on the transaction size per order. We define $size_{n,t}$ as the average transaction size of bond n traded on day t. The total traded amount of a bond defined as $tradeda_{n,t}$ as the cumulative amounts of bond n traded on day t in the repo market. A larger traded amount suggests that more borrowers and lenders meet in the repo market that day. Repo specialness is sensitive to the JGB auction cycle, as indicated in the literature on US Treasury bonds (e.g., Sundaresan (1994), Keane (1995), D'Amico et al. (2018); see also Section A in the Appendix). To control for this effect, we use an on-the-run dummy, *ontherun*, for the most recently issued bond; an ex-on-the-run dummy, *exontherun*, for the second most recently issued bond; and *age*, which is defined as the number of years

[8]The BoJ does not disclose its purchase amounts for each operation, but it periodically discloses its JGB holding amounts. Before May 2014, the announcement frequency was once a month, and, since then, three times a month. Since the information's periodicity is longer than the period between two consecutive auctions, the variable $purchase_{n,t}$ represents estimated amounts rather than exact amounts.

since issuance or the most recent reopening. We also construct a dummy variable for the cheapest-to-deliver bond, *ctd*, to control for its active trades. The term $outstanding_{n,t}$ is the logarithm of the outstanding amount of security n on day t.

As Figure 5 shows, repo rates have many spikes, and many of these are on days of high cash demand, such as at the end of quarters and months and in the middle of months. We add date dummies to our panel regression model in Section 5.2 to control for these effects, and other date factors, such as program announcements.

5.2 Empirical results

5.2.1 Effect of scarcity on specialness

In this section, we examine how scarcity reflects borrowing costs, which are the main constituents of cover risk. Figure 5 indicates that, after QQE-II, specialness increases and exhibits larger fluctuations (spikes) than before. These trends can also be confirmed from the descriptive statistics of the GC–SC spread in Table 1. As the table shows, the average of the GC–SC spread in the repo market increased over time, while the median was the largest in NI period and slightly diminished in YCC-I. Some securities may have much greater specialness. The difference between means and medians of specialness widens. We predict that the greater a bond's scarcity, the more difficult the search.

[Table 1 about here.]

We now investigate factors related to the increasing specialness. We estimate a model for initial bid specialness:

$$gcsc_{n,t} \quad = \quad \beta_1 holding_{n,t} + \beta_2 tradeda_{n,t} + \sum_j \gamma_1^j Ages_{n,t}^j + \psi_n + \zeta_t + \epsilon_{n,t} \tag{7}$$

where $gcsc_{n,t}$ is the GC–SC spread at the time of order placement of security n on day t, $holding_{n,t}$ is the BoJ's holding ratio of security n on day t, and $tradeda_{n,t}$ is the traded amount in the repo market of security n on day t. The term $Ages_{n,t}^j$ includes the number of years from the issue or reopening date, $age_{n,t}$; the on-the-run bond dummy $ontherun_{n,t}$; the ex-on-the-run bond dummy $exontherun_{n,t}$; the cross terms $ontherun_{n,t} \times age_{n,t}$ and $exontherun_{n,t} \times age_{n,t}$; and the cheapest-to-deliver bond dummy $ctd_{n,t}$. Our model includes security-level fixed effects (FEs) ψ_n and time dummies ζ_t to control for security- and date-specific effects, respectively. The term $\epsilon_{n,t}$ is the error term.

[Table 2 about here.]

Table 2 shows the results of the initial bid specialness model. The BoJ's bond holding ratios have a significantly positive relation with initial bid specialness after QQE-I. In the NI and YCC-I subperiods, the values of the coefficients range from 20.75 to 25.56, respectively, which is much more than 2.59 in QQE-I. This means that bidders have to raise initial specialness levels due to scarcity concerns after NI. The traded amount has a significantly negative coefficient in QQE-II, but a positive coefficient in NI and in YCC-I. The larger traded amount of a bond suggests its greater availability. The specialness of bonds is low in QQE-II, even though the BoJ expanded annual purchase amounts from ¥50 trillion to ¥80 trillion. However, in the following periods such as NI and YCC, the bond supply cannot keep up with the high borrowing demand, and the specialness of these bonds increases. We control for the effects of bond characteristics, such as age and those of on-the-run and cheapest-to-deliver bonds. After QQE-I, the initial rates of bonds that are on-the-run and ex-on-the-run increase. Additionally, *age* increases initial specialness throughout our subperiods, except for CE-0. The initial specialness of cheapest-to-deliver bonds increases by 8.65 bps in YCC-I, because these bonds were heavily owned by the BoJ at the time of being cheapest to deliver for futures contracts.[9]

5.2.2 Order execution in the repo market

We next present the order/execution results by tracking order IDs.

[Table 3 about here.]

Panel A of Table 3 shows the numbers of orders, Panel B shows the aggregate amounts of order (billions of yen) per trading day, and Panel C shows the respective proportions. During our sample period from CE-0 through YCC-I, the number of filled bid (offer) orders increases substantially, from 64.0 (19.0) to 379.4 (158.0) orders per day. This enormous growth reflects the increasing demand for trading on the electric platform of the Japanese repo market. The speed of growth on the bid side exceeds that on the offer side. The number of bid (offer) cancellations increases from 32.2 (27.5) to 152.5 (195.5) orders per day in the same period. Panel C shows that the probability of execution of bid (offer) orders improves from 65.1% (31.0%) to 69.1% (37.9%) between the CE-0 and YCC-I periods. The unfilled proportion of bid orders rises from 0.4% in CE-0 to 0.8% in YCC-I, and that of offer orders declines from 13.5% to 9.4% in the same period. The increasing proportion of unfilled bid orders could indicate that dealers are finding it difficult to borrow a particular bond in the repo market, whereas the decreasing proportion of unfilled offer orders could indicate strong demand for repo lending.

5.2.3 Estimation of cover risk

Since dealers submit a bid order to cover short, cover risk can be measured by the non-execution ratio of bid orders. As Panel C of Table 3 shows, the non-execution ratio of bid orders rises toward to the end of our sample period, which indicates bond scarcity affects the

[9] In the JGB market, 10-year bonds are traded as cheapest-to-deliver bonds three years after their issuance. The YCC-I period begins in September 2016 and is three years after the introduction of LSAPs, so the BoJ holds a large proportion of cheapest-to-deliver bonds in YCC-I.

non-execution ratio. We then investigate which bonds have higher cover risk. Are bonds with greater scarcity likely to fail to be covered shorts?

[Table 4 about here.]

Table 4 shows the relation between bond scarcity and the order/execution results in the repo market. We calculate the average holding ratio of orders for five- and 10-year JGBs that have frequent transactions. As to the bid orders, the BoJ's holding ratios of bonds averaging over the filled and canceled orders are similar for all subperiods and bond scarcity seem to have little relationship with cancelation. We expect that bidders cancel their orders since they could have found a seller or could have executed in another venue. On the other hand, the BoJ's holding ratios of bonds averaging over unfilled orders are higher than those of filled orders except for CE-0. The scarcity is greater for orders which cannot find lenders. In addition, the gap in holding ratio between filled and unfilled orders is widening. In QQE-I, the holding ratios of filled and unfilled orders are 17.4% and 19.5%, respectively, but in NI, the holding ratios of filled and unfilled orders are 36.2% and 45.2%, respectively, and in YCC-I, they become 47.0% and 58.3%, respectively. The gap expanded to 18.3% in YCC-I, the highest level among the five subperiods, which indicates the scarcity effect increases on the result of a bid order: whether it filled or not. We investigate the formal relation between scarcity and order entry timing in the following section.

We now investigate the determinants of the probability of non-execution. We establish a probit model to predict whether a repo order is executed or not conditional on the central bank holding ratio as a proxy for bond scarcity and the size of bid orders. In the estimation, we again use five- and 10- year JGBs. We further use filled and unfilled orders and exclude canceled orders, since they could have been executed in another venue. The estimation is based on a deal basis data, unlike a daily basis GC–SC spread estimation in Eq. 7. The model is

$$\begin{aligned} P(y_{n,t,s}=1) &= \Phi(\beta_0 + \beta_1 holding_{n,t} + \beta_2 size_{n,t,s} + \beta_3 after1520_{n,t,s} \\ &\quad \sum_j \gamma_1^j Ages_{n,t}^j + \beta_4 outstanding_{n,t} + maturity_n + \zeta_t) \end{aligned} \tag{8}$$

where $y_{n,t,s}$ is a binary variable that equals one if order s of security n on date t is neither executed nor canceled before market close, and zero otherwise; $\Phi(\cdot)$ is the cumulative normal probability density function; $holding_{n,t}$ is the BoJ's holding ratio of security n on day t; $size_{n,t,s}$ is the ordered amount of order s in the repo market of security n on day t; and $after1520_{n,t,s}$ is a dummy variable for orders placed after 3:20 p.m.[10] The term $Ages_{n,t}^j$ includes the number of years since the issue or reopening date, $age_{n,t}$; the on-the-run bond dummy $ontherun_{n,t}$; the ex-on-the-run bond dummy $exontherun_{n,t}$; and the cheapest-to-deliver bond dummy $ctd_{n,t}$. The variable $outstanding_{n,t}$ is the logarithm of the outstanding amount of security n on day

[10] The largest trading platform for JGB spot trading provided by Japan Bond Trading Co., Ltd. ends the afternoon session at 3:20 p.m. The repo traded amount decreases and the unfilled ratio increases after around that time.

t. Our model includes time dummies ζ_t to control for date-specific effects and maturity-level fixed effects $maturity_n$.

[Table 5 about here.]

Panel A of Table 5 reports the maximum likelihood estimation results of a panel probit model for the five subperiods. The upper panel presents the coefficient estimates and the lower panel presents the mean unfilled probabilities and the marginal effects of *holding* and *size* calculated from the model estimates at the sample mean.

Consistent with our expectations, the coefficients of the BoJ's holding ratio are positive and significant in QQE-I, QQE-II, and YCC-I. The marginal effect shows the probability of non-execution rises by 0.11% in QQE-II, and by 0.45% in YCC-I as the holding ratio increases by 10%. The size ordered has a positive impact on the determination of execution/non-execution in NI and YCC-I. The probability of non-execution increases with larger ordered amounts. The average of predicted probability of non-execution is 0.67% in QQE-I, and it rises to 1.86% in YCC-I. Cover risk rises according to the increasing scarcity in the JGB market, as expected.

We now consider the relation between cover risk and the borrowing fee in the repo market. When entering an order in the repo market, a short seller could predict the probability of execution and decide on the bid rate based on the information such as scarcity on that bond. Therefore, we expect that the higher the probability of non-execution, the greater the GC–SC spread. We regress the model's predicted probability of non-execution on the GC–SC spread based on the panel probit model in Eq. (8):

$$gcsc_{n,t,s} = \beta_0 + \beta_1 \hat{P}(y_{n,t,s} = 1) + \epsilon_{n,t,s} \tag{9}$$

where $gcsc_{n,t,s}$ is the GC–SC spread, $\hat{P}(y_{n,t,s} = 1)$ is the model's estimated probability of non-execution of order s of security n on day t, and $\epsilon_{n,t,s}$ is the error term.

Panel B of Table 5 presents the regression results of a linear regression model for the five subperiods. The coefficient estimate for the probability of non-execution is significantly positive for all the periods except CE-0, as expected. The results indicate that dealers' orders with 7.7 bps (7.8 bps) more specialness have a 10% lower probability of execution in NI (YCC-I). The magnitude of specialness increases with higher cover risk, but it is also determined by other factors specific to the security.

5.2.4 Bargaining power of borrowers and lenders

The search-theoretic model in Sections 4.1 and 4.2 predicts that the degree of specialness is higher when a short seller submits a bid for a bond of greater scarcity. Even if the short seller posts a rate with high specialness (a low SC rate), it could take longer to find a rate that a counterparty will accept, and the short seller might have to increase the specialness in the course of negotiation. Intraday repo data allow us to track the negotiation processes of bids and offers that take place in the screen-based repo market. We compare initial and final specialness and the time needed to reach the execution rate. The rate concession is defined as the difference between the initial and final specialness of orders. We measure the negotiation time, defined as the time between an order's entry and its execution or cancellation or market closure (6 p.m.).

Table 6 shows the rate concessions for filled, canceled, and unfilled orders separately. The significance of the Welch two-sample t-test, whose alternative hypothesis is that the true difference between the initial and final rates in means is not equal to zero, is indicated by asterisks in the rate concession columns.

[Table 6 about here.]

In Panel A of Table 6, the differences between the initial and final GC–SC spreads for bid orders are significant at the 1% level in all periods except CE-0, and these differences for offer orders are significant in NI and YCC-I. The absolute values of the rate concession amounts are larger for bid orders than those for offer orders. We now test Hypothesis 3. In our search-theoretic model, if a repo transaction occurs, the lending fee is set so that the lender receives a fraction $\phi \in [0,\ 1]$ and the borrower receivers $1 - \phi$ of the total surplus. If borrowers' and lenders' bargaining power are even ($\phi = 0.5$), they will make mutual concessions. If borrowers' bargaining power weakens ($\phi < 0.5$), they will have to make greater concessions. We consider the absolute values of rate concession amounts for bid (offer) orders as the indicator of bargaining power of the lenders (borrowers). The borrower's bargaining power ϕ is then estimated by the ratio of the absolute value of the rate concession amounts for offer orders to the aggregate rate concession amounts for bid and offer orders. The estimate is 0.31 in NI to 0.42 in YCC-I, which is lower than 0.5. This result indicates that the aggressive stance of the offer side and the bargaining power of lenders is stronger than the borrower, reflecting of the increasing scarcity of government bonds. The effect of scarcity is greater for bid orders than for offer orders. It is interesting to note that the level of the final offer rates is higher than that of the final bid rates in all the subperiods.

The two rightmost columns of Table 6 present the average negotiation times. The elapsed time until execution for bid orders increases from 8.9 minutes in CE-0 to 13.1 minutes in NI and then slightly declines in YCC-I, which indicates bidders' increasing difficulty finding counterparties. On the other hand, the average elapsed times of the offer orders decrease after the introduction of the QQE. Security collateral financing in the repo market became easier after the implementation of the LSAP program. These results support Hypothesis 2.

Panel B of Table 6 shows the results of the analysis of canceled orders. Similarly, the differences between the initial and final GC–SC spreads for bid orders are significant at 5% in QQE-I, at 1% in QQE-II and NI, and at 10% in YCC-I, and the differences for the offer orders are nonsignificant in all periods. The rate concession amounts for canceled bid orders are smaller than those for filled orders. Even though an electronic platform is a convenient and efficient way of disseminating trading needs, it is limited in terms of the variety of participants. Some buy-side investors, such as insurance companies, prefer a voice market to an electronic platform. Therefore, dealers might contact multiple venues to check the rates and available quantities of bonds they need to trade. Canceled orders thus reveal the scarcity effect more broadly. The final specialness of canceled orders is significantly lower than for executed orders, as determined by Welch t-tests, not shown in Table 6. A trader placing orders in multiple venues will take a better rate if one is found in another market. This is one of the reasons why the average final specialness of canceled orders is lower than for filled orders. However, the elapsed time until cancellation is twice as long as for filled orders.

In the case of unfilled orders in Panel C of Table 6, the rate concessions are much higher than in Panels A and B. Order submitters are aware of the difficulty locating counterparties for these bonds, and they raise the degree of specialness further and wait longer. The average elapsed times for unfilled orders are 120.8 minutes in CE-0 and 163.7 minutes in NI. This result indicates that order submitters cannot find a counterparty in any venue and therefore leave the orders until the official market closes.

5.2.5 Mispricing, rate concession, and negotiation times

We next construct a model for the rate concession between a bid order entry and its execution. What factors are related to these rate changes?

The rate concession of the GC–SC rate and the search time depend on the first rate an order submitter posts. The posted rate can be above or below market expectation. The larger (smaller) the initial GC–SC spread, the larger (smaller) the rate concession. Additionally, the larger (smaller) the initial GC–SC spread, the longer (shorter) the search time. We estimate the market expected rate from the GC–SC model in Eq. (7). In the analysis on rate concessions and search times, we include a variable for mispricing that captures the deviation of the initial specialness from market expectations. The mispricing is defined as the difference between the observed GC–SC spread and the estimated GC–SC model in Eq. (7). This mispricing indicates whether the initial bid specialness is higher or lower than the model forecast. Our panel regression model is therefore as follows:

$$\begin{aligned} chgrate_{n,t} \;=\; & \beta_1 holding_{n,t} + \beta_2 tradeda_{n,t} + \beta_3 mispricing_{n,t} \\ & + \sum_j \gamma_1^j Ages_{n,t}^j + \psi_n + \zeta_t + \epsilon_{n,t} \end{aligned} \tag{10}$$

where $chgrate_{n,t}$ is the rate concession between the order placement and execution of security n on day t. The regressors are the BoJ's holding ratio, $holding_{n,t}$; the traded amount in the repo market, $tradeda_{n,t}$; the mispricing of the GC–SC spread model, $mispricing_{n,t}$; and the variables included in the term $Ages_{n,t}^j$. Our model again includes security-level fixed effects ψ_n and time dummies ζ_t to control for security- and date-specific effects, respectively. The term $\epsilon_{n,t}$ is the error term.

[Table 7 about here.]

Table 7 presents the results for the time and security fixed panel regressions of the rate concession for filled orders in the five subperiods. The dependent variable is the change between the initial bid rate and the final (execution) rate. We are most interested in the impact of mispricing in the initial GC–SC spread on rate concession. The coefficients for the mispricing of the initial GC–SC spread are significantly positive in the CE-0, QQE-II, and NI periods. An order placed at a level lower than the model's prediction of specialness for that bond needs a greater degree of concession, as expected.

Although the BoJ's holding ratio of a bond does not have significant explanatory power before QQE-II, its coefficient becomes significant and positive in NI and YCC-I. Short sellers have to concede a higher rate to execute highly scarce bonds.

The traded amount has a significant and negative coefficient in all the subperiods. Larger traded amounts indicate the bond's better tradability, which means the many lenders and borrowers are participating in the repo market. There are two reasons why larger rate concessions are not necessarily for bonds with many transactions. First, a dealer can easily predict rates for bonds with many transactions, so the initial rate is originally a rate that reflects the market situation. Second, there are many lenders and borrowers, so they are more likely to find each other in the repo market. The negative relation between trading volume and rate concession is observed throughout our sample period.

Next, we estimate a model for search time with the same sets of explanatory variables as in Eq. (10). We replace the dependent variable $chgrate_{n,t}$ in Eq. (10) with $etime_{n,t}$, the time elapsed until the execution of security n on day t, and we repeat the two-way fixed regression.

[Table 8 about here.]

Table 8 presents the results for the regression of the negotiation times for the filled bid orders in the five subperiods. The dependent variable is the time elapsed between the bid order placement and its execution, and the explanatory variables are the same as in Eq. (7). The coefficients of the BoJ's holding ratio until QQE-II are nonsignificant and become significantly positive after NI. The results indicate that the higher the BoJ's holding ratio, the longer the negotiation time. The coefficient estimates for NI and YCC-I are 23.514 and 8.520, respectively, which indicates that the search time increases by about 2.3 minutes and 0.85 minutes in NI and YCC-I as the BoJ holding ratio rises by 10%. Bond scarcity increases search times in the repo market, just as our search-theoretic model predicted. The amounts traded in the repo market have negative coefficient estimates in all the subperiods after QQE-I. The larger the amount traded in the repo market, the shorter the search time for filled orders. Large trade volumes indicate the better availability of a specific bond. Since bonds with large trade volumes have a lower mismatch rate and many lenders and borrowers are in the repo market, a dealer can find a counterparty in less time. The coefficients for the mispricing of the initial GC–SC spread model are significant in the QQE-I, QQE-II, and NI periods. An order placed at a level lower than the valid specialness for that bond needs more time to be executed, as expected.

The results in this section support our hypothesis that the central bank's LSAPs increase cover risk as measured by negotiation, even for filled orders.

5.2.6 Impact of the central bank's purchase operations

We now consider another effect of the central bank's LSAPs. Each central bank purchase operation influences dealer activity in the repo market. When the BoJ purchases JGBs in its operations, it conducts an auction through its financial network system. The BoJ announces an auction to primary dealers at 10:10 a.m. and accepts their bids until 11:40 a.m.; the bidders are then notified of the results around 12:00 p.m. and the settlements are made in two business days.[11]

If an auction bidder does not hold the bond to be sold to the central bank, the bidder needs to locate the bond in the repo market. Given greater scarcity, a dealer with a short position will be forced to spend longer locating a specific bond and to pay higher prices than the initial price to avoid failure to deliver. Our sample covers orders placed after 12:20 p.m. in the repo market. Bid orders from short sellers according to the purchase operations are included among the orders on the days of the operations. We investigate the effects of the purchase operations on specialness and dealer search frictions.

We first investigate the GC–SC spread at the time of order placement and rate concessions (the differences between the initial and last rates for each order). Since demand for the bond purchased by the central bank is expected to increase, its borrowing costs will rise that day. We first look at the initial GC–SC spread and rate concession for filled, canceled, and unfilled orders separately and then examine the impact of each purchase operation on borrowing and search costs.

[Table 9 about here.]

Table 9 shows the average GC–SC spread of bid orders and the rate concession from the time of order placement to execution, cancellation, or market close. The average GC–SC spread of the bid orders is lower for purchased bonds in CE-0 and QQE-I, but increases after QQE-II (Panel A). The rate difference between bonds that were purchased by the central bank's operation and those that were not purchased increases to 1.12 bps in NI and then declines to 0.57 bps. Bond specialness increases as a result of the central bank's purchase operation.

The rate concession for purchased bonds is greater than for bonds that were not purchased by the BoJ in the last three periods. The results indicate that it becomes increasingly difficult after QQE-II to execute a bid order for bonds purchased by the central bank. Each central bank purchase operation increases the cover risk. Panel B shows that the rate change for canceled orders is smaller than for filled orders whether the BoJ purchases the bond or not, except in CE-0. This result suggests that the cancellation occurred because the bidders located the specific bonds in other venues.

We now formally investigate the impact of each purchase operation. We add the variable $purchase_{n,t}$, the amount of security n purchased by the central bank during t, to Eq. (7) or

[11] Following the shortening of the JGB settlement cycle to $T+1$ on May 1, 2018, the BoJ shortened the settlement cycle of its JGB purchases from two business days ($T+2$) to one business day ($T+1$). Our sample period is prior to this system change.

(10), and we repeat the regression with time and security fixed effects:

$$\begin{aligned} gcsc_{n,t} &= \beta_1 holding_{n,t} + \beta_2 tradeda_{n,t} + \beta_4 purchase_{n,t} \\ &\quad + \sum_j \gamma_1^j Ages_{n,t}^j + \psi_n + \zeta_t + \epsilon_{n,t} \end{aligned} \tag{11}$$

$$\begin{aligned} chgrate_{n,t} &= \beta_1 holding_{n,t} + \beta_2 tradeda_{n,t} + \beta_3 mispricing_{n,t} + \beta_4 purchase_{n,t} \\ &\quad + \sum_j \gamma_1^j Ages_{n,t}^j + \psi_n + \zeta_t + \epsilon_{n,t} \end{aligned} \tag{12}$$

[Table 10 about here.]

[Table 11 about here.]

Tables 10 and 11 present the impact of the central bank's purchase operations on the new ordered specialness and rate concessions, respectively. We obtain a significant positive coefficient for the purchased amount in NI (Table 10). The larger the amounts of a bond the central bank purchases, the higher the specialness at bid order entry in NI. The costs to cover the short position increase for bonds purchased by the central bank. In Table 11, the coefficients for the purchased amounts are significant in QQE-II and YCC-I. The bonds purchased by the central bank have higher concession rates due to their higher demand in the two subperiods. On the other hand, for the NI period, where the initial specialness is significantly high for the purchased bonds, the purchased amounts have no further effect on the rate concession. Hypothesis 4 is supported for partial subperiods.

5.2.7 Impact of the central bank's lending facility

We now examine the interaction between rates in the central bank's SLF and the repo market. As noted in Section 3.3, the BoJ facilitates lending bonds in a manner that is complement to repo transactions. After February 2016, the rate set by the BoJ link to uncollateralized overnight call rate so that the actual lending rates fluctuate around −50 to −60 bps. If the SC rate in the repo market is lower than −50 bps (or −60 bps), borrowing from the BoJ becomes reasonable choice for dealers. Therefore, the SC rate have a ceiling imposed by the SLF.

We investigate the ceiling effect of the central bank's SLF by testing whether the rate concession is smaller when the ordered SC rate is around −50 bps. We add six dummies to Eq. (10) to represents the SC rate levels:

$$\begin{aligned} chgrate_{n,t} &= \beta_0 + \beta_1 holding_{n,t} + \beta_2 tradeda_{n,t} \\ &\quad + \sum_j \gamma_1^j Ages_{n,t}^j + \sum_k \gamma_2^k Dsc_{n,t}^k + maturity_n + \zeta_t + \epsilon_{n,t} \end{aligned} \tag{13}$$

where $chgrate_{n,t}$ is the rate concession between the order placement and execution of security n on day t, and $Dsc_{n,t}^j$ includes six dummy variables: $d_{-20 \leq sc < -10}$, $d_{-30 \leq sc < -20}$, $d_{-40 \leq sc < -30}$,

$d_{-50\leq sc<-40}$, $d_{-60\leq sc<-50}$, and $d_{sc\leq -60}$, where each dummy variable equals one when the SC rate upon order entry ranges between the dummy's subscript values. We expect smaller coefficients for dummies $d_{-60\leq sc<-50}$ and $d_{sc\leq -60}$ compared to those for other dummies. The other explanatory variables are the same as in Eq. (7), except we exclude *mispricing* and replace security-level fixed effects with maturity-level fixed effects $maturity_n$. We perform the regressions for the periods after February 2016, when the BoJ started to set the upper fee according to the overnight call rate and began disclosing its average lending rates.

[Table 12 about here.]

Table 12 reports the results of panel regressions of the central bank's lending facility on SC repo rate concession. All the dummies of the rate below −20bps are significant in YCC-I. The coefficient estimates for $d_{-40\leq sc<-30}$ is 0.685 which is the largest and those for $d_{-50\leq sc<-40}$, $d_{-60\leq sc<-50}$, and $d_{sc\leq -60}$ gradually decline. The amount of concession made by bidders diminishes when the SC rates approached to the SLF rate. The coefficient estimate for the dummy below −60bps is −0.5063, where bond borrowers concede little. The result in YCC-I is consistent to the hypothesis that the BoJ's lending facility has a ceiling effect.

On the other hand, in the NI period, a large positive coefficient is estimated for the dummy below −60bps, which indicates that the borrowers concede their ordered rates even if it is more advantageous to borrow the bond through SLF. The lending rate set by the BoJ in the first few months of NI was not stable because the uncollateralized overnight rate fluctuate greatly after the introduction of negative interest rate. There was large uncertainty surrounding the SLF rate on the next day. Dealers are willing to pay slightly more instead of taking risk of unknown SLF rate tomorrow. (See Figure 6.) We estimate for the two distinct subperiods of NI: the 1st period (with large call rate fluctuations), from January 29, 2016 to April 30, 2016; the 2nd period (with stable call rate), from May 1, 2016 to September 20, 2016. The two central columns of Table 12 report the results of panel estimates as in Eq. 13 for the two subperiods of NI. The coefficient estimate for the dummy below −60bps is very large (19.48) and no ceiling effect are estimated in the 1st subperiod with large call rate fluctuations, but in the 2nd subperiod, the coefficient estimates for the dummies between −60bps and −50bps and below −60bps are significantly negative, which indicates dealers choose to forgo borrowing bonds in the repo market and, instead, borrow through the SLF.

[Figure 6 about here.]

6 Concluding remarks

In this study, we investigate cover risk which is the likelihood of short sellers not being able to find a counterparty and its relation with scarcity caused by a central bank's LSAPs. When bond scarcity is high as a result of the LSAPs, a bond dealer who holds a short position will face difficulty finding counterparties. The repo market is a best place to examine characteristics and determinants of cover risk. We build a search-theoretic model and investigate how bond scarcity and demand from short sellers affect specialness and search frictions in the repo market. We incorporate the interactions among short sellers, lenders, and a central bank's lending facility into a search theoretic model and solve the utility functions for the repo borrowing fee. Our model predicts that, given the LSAPs, the borrowing fees will increase and short sellers will need more time to find a counterparty.

Our empirical analyses show that specialness is higher for bonds with greater scarcity. A short seller has to pay a higher borrowing fee to cover a short position when the bond is scarce. Order/execution level data from the JBOND repo platform reveal that specialness increases and the ratio of unfilled orders rises for bonds with greater scarcity. When a bond is severe scarce, a dealer often cannot find a counterparty, even if the dealer posts much higher specialness. We estimate non-execution probability for repo bid orders as a proxy of the cover risk and find that non-execution risk can be an explanatory variable for the bond borrowing fee. We also find that when bond scarcity is high, the price bargaining power of lenders is stronger than the borrowers, and underestimation (mispricing) of bid prices by short sellers increases the amount of rate concession and the length of negotiation. We also investigate the impact of the central bank's purchase operations on repo transactions took place on the same day. The average GC–SC spread of bid orders and the rate concessions increase for bonds purchased by the BoJ after QQE-II sub-periods. The central bank's lending facility has a ceiling effect on the SC repo rate for highly scarce bonds. In the period after September 2016, the SC rate is less likely to be lower than the lending rate through the SLF, which indicates that a dealer could give up on executing his/her order in the repo market, intending to borrow the bond from the central bank. Our results suggest that the repo rates are sensitive to the fees the central bank impose for its lending facility. Determination of the SLF rate may create a ceiling of the repo rate. The overall results suggest that an aggressive QE carried out by the central bank weakens dealers' market-making capability.

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A Relation between the GC–SC spread and age

In this section, we examine at the relation between the GC–SC spread of an individual bond and its age since issuance. As shown by Sundaresan (1994), Keane (1995), and D'Amico et al. (2018), the SC repo rates in the United States tend to spike downward at regular intervals, based on the auction cycle of US Treasury bonds. These studies note that, during a typical auction cycle, the supply of Treasury collateral available to the repo market is at its highest level when the security is issued and, therefore, the GC–SC spread should be close to zero. As time passes, more and more of the security can be purchased by holders who are not very active in the repo market; consequently, the security's availability can decline over time, and the repo specialness spread can increase. At the next security auction, holders of short positions will usually roll out of the outstanding issue, implying that demand for that specific collateral should decrease and that the repo specialness spread will rapidly decline.

[Figure 7 about here.]

We examine whether the auction cycle of JGBs will cause rises and falls in repo specialness in Japan. The panels of Figure 7 illustrate the auction cycle dynamics of the GC–SC spreads by showing their averages as a function of age (years since issuance). Since the auction cycles differ according to the original maturities, we calculate them for two-, five-, 10-, 20-, and 30-year bonds separately.

The panel for the two-year bond is different because of its monthly auction cycle without reopening. The GC–SC spreads increase as time passes, but they do not narrow, even after the issuance of the next two-year bond. The panels for the five-, 10-, 20-, and 30-year bonds show similar trends. Generally, the Japanese Ministry of Finance issues five-, 10-, 20-, and 30-year bonds quarterly and conducts two regular reopenings following each issuance. We can observe three separate auction subcycles: the dramatic run-up in the specialness spread before the first reopening; a second run-up, similar in shape but of smaller magnitude, immediately follows and peaks just before the second reopening; and, during the third subcycle, the specialness spread exhibits various levels, depending on the original maturity. This result suggests that the increased availability of on-the-run securities after each reopening diminishes the impact of the seasonal demand for short positions around these dates.

Figure 1: BoJ's monthly purchase amounts of nominal JGBs (in trillions of yen)
The gray areas indicate the BoJ's monthly purchase amounts (in trillions of yen, left axis) of two- and five-year bonds (mid term), 10-year bonds (long term), and 20-, 30-, and 40-year bonds (super long term). We calculate these by the increments of the amounts the BoJ holds. The red line indicates the BoJ's holding ratio (as a percentage) of nominal JGBs (right axis). Our data consist of the amounts of all nominal JGBs with a fixed-rate coupon held by the BoJ from January 2012 to April 2018.

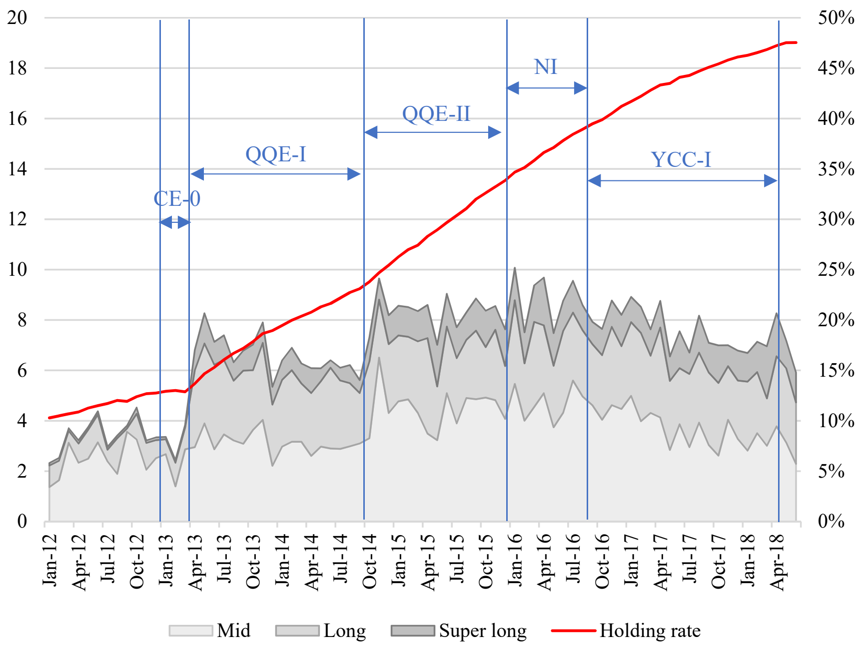

Figure 2: Flows in the bond lending market
This figure shows the flows in the bond lending market. Investors in the bond lending market are short sellers with measures α_{ss}, lenders with measures α_l, and a central bank. A short seller can borrow a bond from a lender for a fee ω in the repo market or from the central bank for sl.

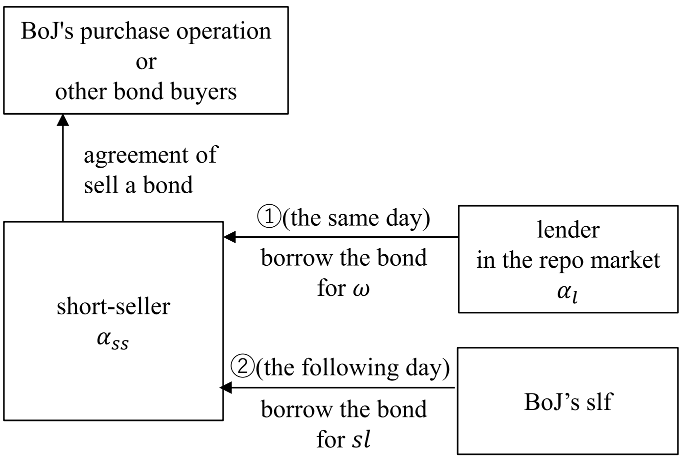

Figure 3: Lending fee as a function of the measures of lenders and short sellers
This figure illustrates the dependence of the lending fee on the measures of lenders and short sellers. The top panel shows the lending fee, ω, as a function of the lender measure, α_l, and the bottom shows the lending fee, ω, as a function of the short seller measure, α_{ss}. We set the parameter values of Eq. (5) as follows: $\phi = 0.5$, $h_s = 0.001$, $sl = 0.005$, $h_f = 0.01$, $e_l = 0.0001$, $\delta = 0.99$, $\lambda = 100$, and $r = -0.0005$.

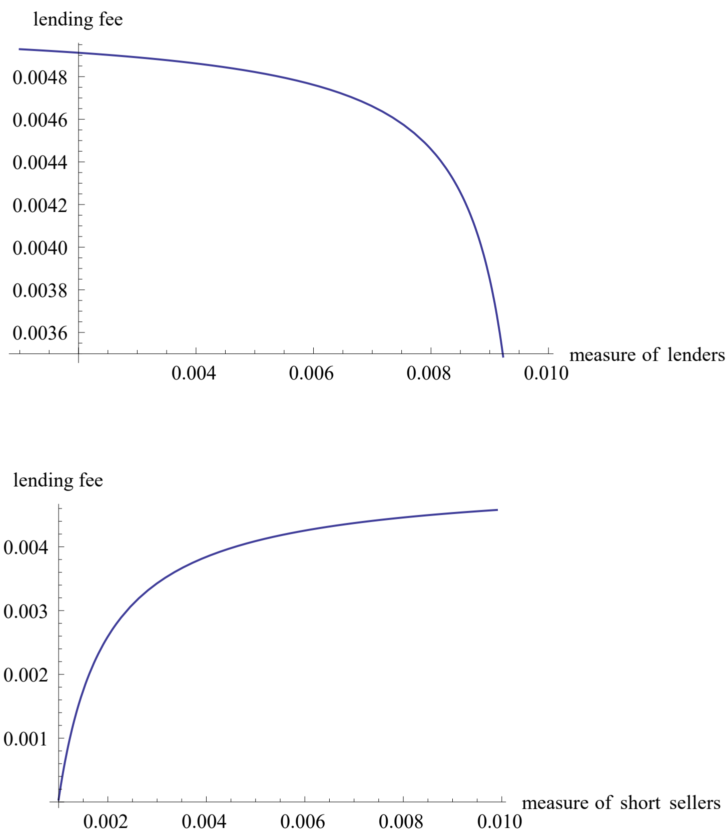

Figure 4: Lending fees for different bargaining power

This figure illustrates the lending fees for different bargaining power levels and for different lending fee levels of the central bank. The top panel shows the lending fee, ω, as a function of the lender measure, α_l for four different bargaining powers of borrowers, $\phi = 0.3$, $\phi = 0.4$, $\phi = 0.5$, and $\phi = 0.6$. The bottom panel shows the lending fee, ω, as a function of the lender measure, α_l for three different lending fees through the SLF, $sl = 0.004$, $sl = 0.005$, and $sl = 0.006$. We set the parameter values of Eq. (5) as follows: $h_s = 0.001$, $h_f = 0.01$, $e_l = 0.00001$, $\delta = 0.99$, $\lambda = 100$, $\alpha_{ss} = 0.008$, and $r = -0.0005$.

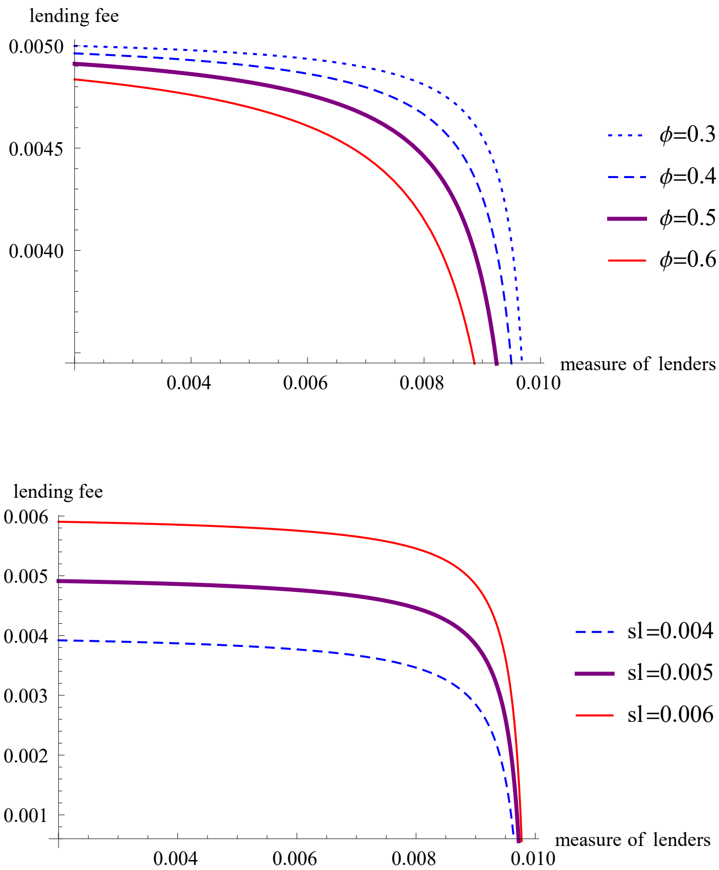

Figure 5: Historical GC–SC spread

This figure shows the time-series evolution of the GC–SC spread (in bps). The GC–SC repo rate is obtained from JBOND and covers the period from January 4, 2013, to April 30, 2018. Our daily average SC rate is the weighted average of the SC rate obtained by weighting each traded rate by the traded amount. The Tokyo Repo Rate is used as the GC rate.

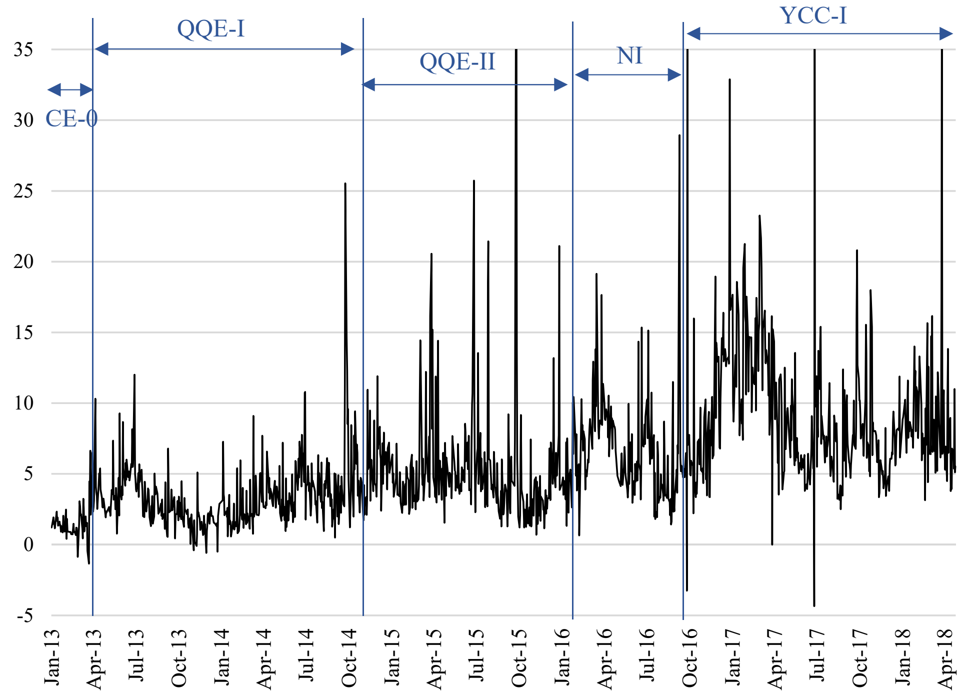

Figure 6: Historical uncollateralized overnight call rate
This figure shows the time-series evolution of the uncollateralized overnight call rate (in bps). The uncollateralized overnight call rate is obtained from the BoJ and covers the period from January 4, 2013, to April 30, 2018.

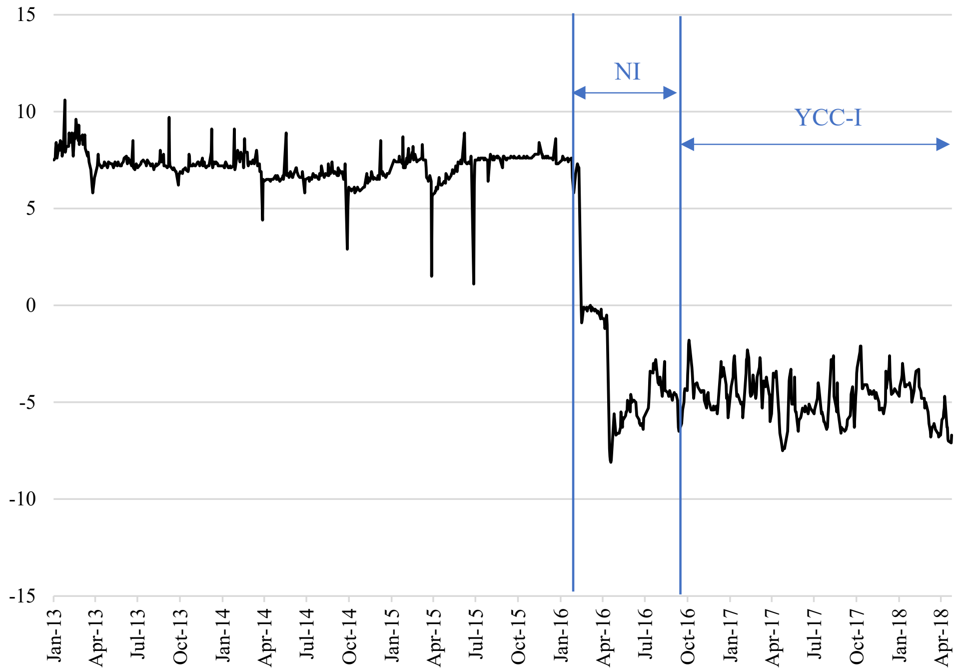

Figure 7: GC–SC spread since issuance and reopening dates

These panels plot the average GC–SC spreads (in bps) as a function of age since issuance. We show the spreads for two-, five-, 10-, 20-, and 30-year bonds separately. The blue solid vertical lines indicate the timing of the next issue of a bond with the same maturity, and the red dotted vertical lines indicate the first and second reopenings. The 40-year bond has various reopening times, so we do not show its panel in this figure.

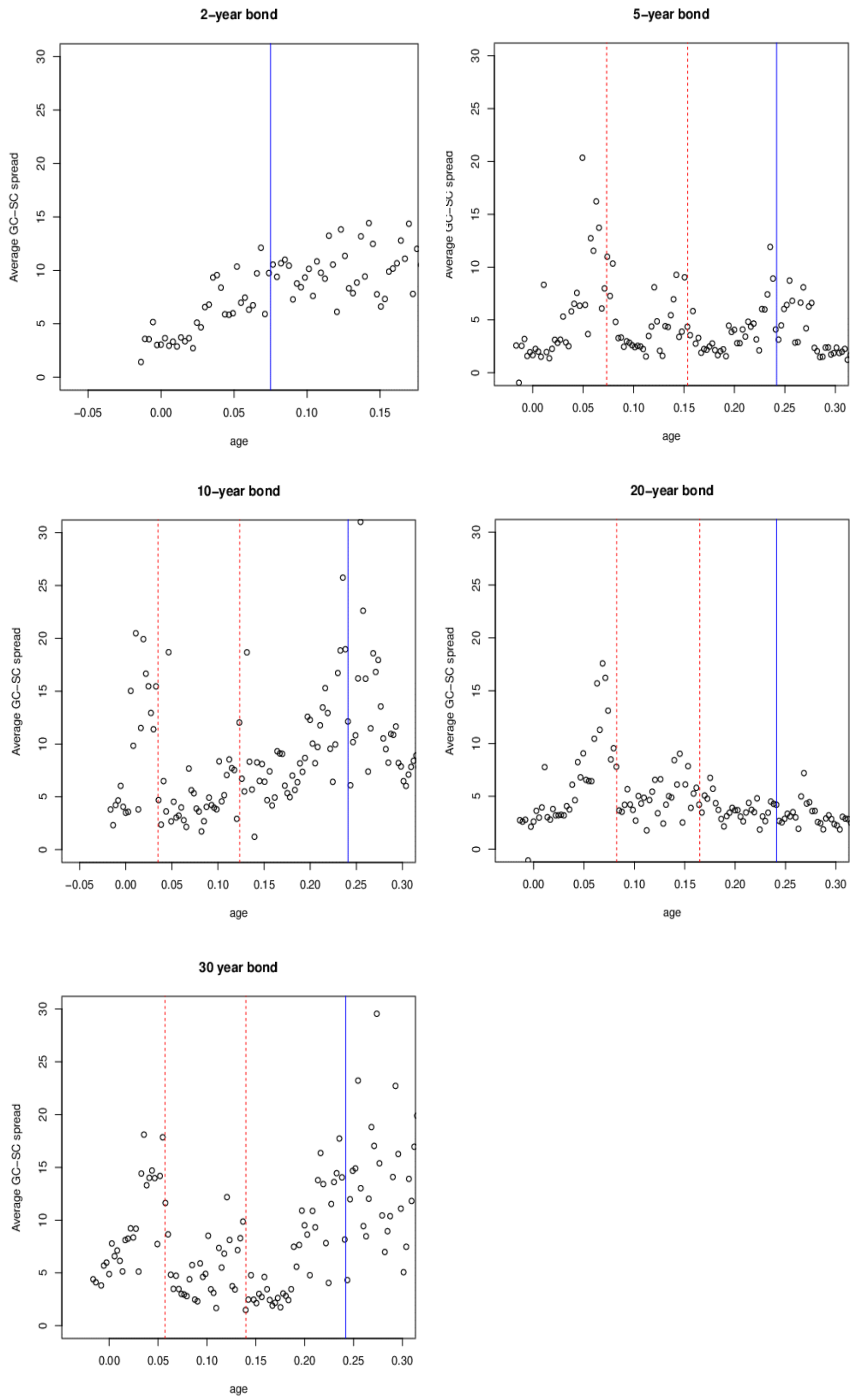

Table 1. Descriptive statistics of the GC–SC spread

This table shows the average, median, and standard deviation of the GC–SC spread (in bps). The CE-0 period is from January 1, 2013, to April 3, 2013; the QQE-I period is from April 4, 2013, to October 30, 2014; the QQE-II period is from October 31, 2014, to January 28, 2016; the NI period is from January 29, 2016, to September 20, 2016; and the YCC-I period is from September 21, 2016, to April 30, 2018.

	Mean	Median	Std. Dev.	Observation
CE-0	1.69	1.00	3.13	2129
QQE-I	2.70	1.70	5.58	19083
QQE-II	3.89	2.50	5.70	18160
NI	4.77	2.66	7.20	14034
YCC-I	5.28	2.31	8.66	30036

Table 2. Panel regression of the specialness of new orders

This table presents the results for the regression of the GC–SC spreads. The dependent variable is the GC–SC spread (in bps) and the regression equation is Eq. (7). Security-level fixed effects and daily time dummies are not shown. The t-values are in parentheses and are calculated for cluster-robust standard errors. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	CE-0		QQE-I		QQE-II		NI		YCC-I	
holding	0.101		2.5872	***	20.747	***	21.144	***	25.561	***
	(0.01)		(5.96)		(29.71)		(13.67)		(30.35)	
tradeda	−0.1814	**	0.0156		−0.0720	***	0.0885	**	0.1660	***
	(−2.02)		(0.89)		(−3.13)		(2.35)		(5.49)	
ontherun	2.0419	**	0.4079	**	1.6964	***	0.2227		6.6254	***
	(2.12)		(2.07)		(5.81)		(0.34)		(19.53)	
exontherun	5.0813	***	0.9889	***	2.0009	***	6.2185	***	7.0379	***
	(4.95)		(5.54)		(7.38)		(9.73)		(22.32)	
age	7.94		5.8508	***	14.451	***	17.652	***	34.901	***
	(1.29)		(7.11)		(13.38)		(4.96)		(19.18)	
ontherun × *age*	−0.040		26.323	***	40.626	***	40.419	***	6.6656	***
	(−0.01)		(10.94)		(14.09)		(7.34)		(4.21)	
exontherun × *age*	−16.895	***	3.0877	***	4.334	***	−19.768	***	−6.8447	***
	(−4.45)		(4.49)		(4.53)		(−8.25)		(−7.98)	
ctd	0.510		3.1408	***	1.4967	***	0.4322		8.6459	***
	(0.49)		(19.26)		(6.25)		(0.88)		(25.49)	
Time FE	Yes		Yes		Yes		Yes		Yes	
Security FE	Yes		Yes		Yes		Yes		Yes	
R-Squared	0.3584		0.6298		0.7362		0.6722		0.6333	
Adjusted R-squared	0.3016		0.6196		0.7300		0.6645		0.6265	
F-Statistic	6.316		61.580		119.600		88.150		94.140	
Observations	2129		19083		18160		14034		30036	

Table 3. Order Execution

Tables below show the numbers and amounts of order execution per trading day. Panel A shows the total numbers of orders and their breakdown of filled, canceled, and unfilled orders per day. Panel B shows the total amounts of orders (in billions of yen) and their breakdown of filled, canceled, and unfilled per day, and Panel C shows the respective proportions (%). We compute the statistics of for bid and offer orders separately. The statistics for bid orders are presented in the left-hand columns, and those for offer orders are presented in the right-hand columns.

Panel A: Number of orders

	BID				OFFER			
	Total	Filled	Canceled	Unfilled	Total	Filled	Canceled	Unfilled
CE-0	96.2	64.0	32.2	0.0	46.6	19.0	27.5	0.0
QQE-I	191.6	131.9	59.7	0.1	68.5	29.0	38.5	1.1
QQE-II	330.1	224.0	105.5	0.6	137.8	48.8	70.1	18.9
NI	490.3	335.3	153.3	1.7	320.8	106.3	178.8	35.7
YCC-I	532.9	379.4	152.5	0.9	367.1	158.0	195.5	13.5

Panel B: Ordered amount

	BID				OFFER			
	Total	Filled	Canceled	Unfilled	Total	Filled	Canceled	Unfilled
CE-0	374	243	129	1.5	229.1	71	127	31
QQE-I	583	392	190	1.3	293.2	95	144	54
QQE-II	881	617	263	1.4	455.1	150	230	75
NI	1175	796	372	7.4	942.3	297	502	144
YCC-I	1344	928	405	10.6	1109.1	421	584	104

Panel C: Filled proportion

	BID			OFFER		
	Filled	Canceled	Unfilled	Traded	Canceled	Unfilled
CE-0	65.1%	34.5%	0.4%	31.0%	55.5%	13.5%
QQE-I	67.2%	32.5%	0.2%	32.4%	49.1%	18.5%
QQE-II	70.0%	29.9%	0.2%	33.0%	50.4%	16.5%
NI	67.7%	31.6%	0.6%	31.5%	53.2%	15.3%
YCC-I	69.1%	30.2%	0.8%	37.9%	52.6%	9.4%

Table 4. Central bank's holding ratio of bonds filled, canceled and unfilled orders
This table presents the BoJ's holding ratio of bonds averaging over the filled, canceled, and unfilled orders in each subperiod. We calculate bid initiated and offer initiated orders separately. Our data consist of orders for five- and 10-year bonds placed after 12:20 p.m. between January 2013 and April 2018.

	BID			OFFER		
	Filled	Canceled	Unfilled	Traded	Canceled	Unfilled
CE-0	6.4%	5.0%	4.4%	5.1%	5.5%	3.6%
QQE-I	17.4%	18.2%	19.5%	18.1%	17.6%	18.0%
QQE-II	31.2%	30.2%	36.7%	34.7%	31.7%	31.8%
NI	36.2%	35.6%	45.2%	40.6%	34.6%	42.0%
YCC-I	47.0%	48.6%	58.3%	51.2%	42.8%	53.2%

Note: We define bid (offer) initiated orders when an order execution is triggered by bid (offer) orders.

Table 5. Probability of non-execution
Panel A presents the results for the panel probit regression of the probability of non-execution. The dependent variable is a binary variable that equals one if and only if the order remains un-executed until market close, and the explanatory variables are presented in Eq. (8). Maturity-level fixed effects and daily time dummies are not shown. The z-values are in parentheses. The means of the predicted non-execution probabilities are presented in the Avr. non-execution rate column, and the marginal effects (MEs) of *holding* and *size* are presented in the last two columns. Panel B presents the regression results between the GC–SC spread in Eq. 9 and non-execution probability. The dependent variable is the GC–SC spread in bps, and the explanatory variable is the predicted probability of non-execution based on the probit regression. The t-values are in parentheses. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Panel probit regression of the probability of non-execution

	CE-0	QQE-I	QQE-II	NI	YCC-I
holding	−0.222	0.876***	2.085***	0.306	2.417***
	(−0.14)	(2.89)	(6.34)	(0.87)	(14.60)
size	−0.003	0.000	−0.005***	0.006***	0.003***
	(−0.75)	(0.24)	(−3.12)	(6.36)	(7.35)
ontherun	1.429***	0.754***	0.566***	0.750***	0.724***
	(2.79)	(5.42)	(3.53)	(3.60)	(9.77)
exontherun	1.829***	0.208	0.590***	0.546***	0.488***
	(3.66)	(1.39)	(4.22)	(3.98)	(9.03)
age	0.211*	−0.027	0.015	−0.106*	0.0941***
	(1.94)	(−0.84)	(0.34)	(−1.82)	(5.61)
ctd	−0.112	0.122	−0.149	0.662***	−0.351***
	(−0.31)	(1.31)	(−1.50)	(6.03)	(−10.36)
outstanding	−3.995	0.512***	0.454**	−4.865	0.339***
	(0.00)	(3.72)	(2.13)	(−0.01)	(6.25)
$after1520$	−0.302	1.4700	1.6970***	1.5040***	1.5780***
	(−0.88)	(14.52)	(18.74)	(14.24)	(42.62)
intercept	−6.561	−1.012	−2.124	−4.126***	0.448
	(0.00)	(−0.97)	(0.00)	(−2.92)	(0.64)
Maturity FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Observation	3471	48471	58275	33971	115377
Wald chi-squared	162.2	752.0	997.7	785.8	4210.2
Pseudo-R-squared	0.53	0.37	0.44	0.42	0.33
Avr. non-execution rate	1.061%	0.666%	0.533%	0.810%	1.860%
ME of *holding*	−0.235%	0.584%***	1.112%***	0.248%	4.496%***
ME of *size*	−0.003%	0.000%	−0.003%***	0.005%***	0.006%***

Panel B: Non-execution probability and the GC–SC spread

	CE-0	QQE-I	QQE-II	NI	YCC-I
$\hat{y}$	15.543***	14.265***	58.772***	76.711***	77.871***
	(4.83)	(7.24)	(21.04)	(24.04)	(60.38)
intercept	1.699***	3.019***	4.555***	4.297***	7.363***
	(28.46)	(134.96)	(157.72)	(114.65)	(205.14)
Adjusted R-squared	0.030	0.006	0.040	0.092	0.079

Table 6. Analysis on order execution process

This table shows the average GC–SC spreads, rate concessions, and elapsed times of order executions. Six leftmost columns show the average GC–SC spreads (in bps) at the time of order entry and at the order execution or cancellation or market close, and the rate differences (rate concessions). We compute the statistics for the bid and offer orders separately. The two groups of three columns show the average elapsed time (in minutes) between the order's placement and its execution or cancellation or market close for bid and offer orders. Panels A, B, and C are separate table for filled, canceled, and unfilled orders, respectively.

Panel A: Filled orders

	BID				OFFER				BID	OFFER
	Initial spread	Final spread	Rate concession		Initial spread	Final spread	Rate concession		Elapsed time	Elapsed time
CE-0	1.61	1.75	0.14		2.38	2.50	0.11		8.9	28.6
QQE-I	2.53	2.74	0.21	***	4.00	3.91	−0.09		11.6	26.6
QQE-II	3.75	4.12	0.37	***	5.65	5.51	−0.14		10.4	20.4
NI	4.52	5.22	0.70	***	6.52	6.20	−0.32	*	13.1	23.8
YCC-I	5.20	5.62	0.41	***	7.10	6.80	−0.30	**	11.1	22.7

Panel B: Canceled orders

	BID				OFFER			BID	OFFER
	Initial spread	Final spread	Rate concession		Initial spread	Final spread	Rate concession	Elapsed time	Elapsed time
CE-0	1.89	1.99	0.10		2.86	2.86	0.00	26.6	56.2
QQE-I	2.63	2.78	0.15	**	4.68	4.63	−0.05	29.5	66.2
QQE-II	3.56	3.77	0.21	***	5.92	5.88	−0.04	24.4	53.4
NI	4.30	4.65	0.35	***	5.94	5.72	−0.23	27.7	54.0
YCC-I	5.48	5.67	0.19	*	6.35	6.23	−0.12	29.1	73.9

Panel C: Unfilled orders

	BID			OFFER			BID	OFFER
	Initial spread	Final spread	Rate concession	Initial spread	Final spread	Rate concession	Elapsed time	Elapsed time
CE-0	3.06	3.09	0.04	2.80	2.83	0.04	120.8	223.6
QQE-I	5.77	6.19	0.43	4.80	4.83	0.02	158.7	240.5
QQE-II	12.11	13.49	1.38	5.37	5.38	0.01	151.0	255.3
NI	22.48	24.36	1.88	6.77	6.75	−0.02	163.7	264.1
YCC-I	21.44	21.95	0.51	8.74	8.70	−0.04	155.4	232.3

Table 7. Panel regression of the rate concession for filled orders
This table presents the results for the regression of the rate concession. The dependent variable is the change in the SC rate until execution (in bps), and the regression equation is presented in Eq. (10). Security-level fixed effects and daily time dummies are not shown. The t-values are in parentheses and are calculated with cluster-robust standard errors. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	CE-0		QQE-I		QQE-II		NI		YCC-I	
holding	−1.072		0.1022		0.4281	*	1.912	***	1.302	***
	(−0.56)		(1.03)		(1.81)		(2.62)		(6.80)	
tradeda	−0.0294	***	−0.0362	***	−0.0727	***	−0.1007	***	−0.1267	***
	(−2.63)		(−9.08)		(−9.34)		(−5.68)		(−18.44)	
mispricing	−0.0087	***	0.0022		−0.0177	***	−0.0348	***	0.0019	
	(−3.08)		(1.32)		(−6.96)		(−8.66)		(1.43)	
ontherun	0.2403	**	−0.0978	**	−0.0335		−0.1554		0.3086	***
	(2.01)		(−2.16)		(−0.34)		(−0.50)		(4.00)	
exontherun	0.14		−0.0743	*	−0.152	*	−0.061		0.259	***
	(1.11)		(−1.82)		(−1.65)		(−0.20)		(3.61)	
age	0.204		0.682	***	−0.711	*	14.290	***	0.6790	
	(0.27)		(3.61)		(−1.95)		(8.53)		(1.64)	
ontherun × *age*	−0.278		1.9557	***	1.083		−3.351		−0.5730	
	(−0.26)		(3.55)		(1.11)		(−1.29)		(−1.59)	
exontherun × *age*	−0.156		0.1985		1.0068	***	0.2306		−0.3919	**
	(−0.33)		(1.26)		(3.11)		(0.20)		(−2.01)	
ctd	0.133		0.0926		0.0449		0.0122		0.1567	**
	(1.03)		(2.48)		(0.55)		(0.05)		(2.03)	
Time FE	Yes		Yes		Yes		Yes		Yes	
Security FE	Yes		Yes		Yes		Yes		Yes	
R-Squared	0.2456		0.2330		0.3591		0.2313		0.1901	
Adjusted R-squared	0.1785		0.2118		0.3441		0.2134		0.1752	
F-Statistic	3.658		10.980		23.950		12.900		12.770	
Observations	2129		19083		18160		14034		30036	

Table 8. Panel regression of the elapsed time until execution
This table presents the results for the regression of the elapsed time until execution. The dependent variable is the time elapsed between the order placement and execution, in minutes, and the explanatory variables are the same as in Eq. (10). Security-level fixed effects and daily time dummies are not shown. The t-values are in parentheses and are calculated with cluster-robust standard errors. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	CE-0		QQE-I		QQE-II		NI		YCC-I	
holding	−71.010		−1.4883		4.6930		23.514	***	8.520	***
	(−1.05)		(−0.54)		(1.59)		(3.95)		(3.78)	
tradeda	−1.0850	***	−1.6131	***	−1.6239	***	−1.7605	***	−2.0396	***
	(−2.73)		(−14.50)		(−16.71)		(−12.16)		(−25.21)	
mispricing	−0.1173		−0.2283	***	−0.1757	***	−0.1934	***	−0.0162	
	(−1.18)		(−4.87)		(−5.54)		(−5.89)		(−1.04)	
ontherun	7.2500	*	−0.4296		−3.2520	***	−5.5851	**	−0.6146	
	(1.71)		(−0.34)		(−2.64)		(−2.20)		(−0.68)	
exontherun	6.15		−0.8243		−4.338	***	0.757		1.347	
	(1.36)		(−0.72)		(−3.79)		(0.31)		(1.60)	
age	16.560		8.618		2.068		65.649	***	6.6119	
	(0.61)		(1.64)		(0.45)		(4.80)		(1.36)	
ontherun × *age*	−36.220		15.8342		14.252		10.409		3.4616	
	(−0.95)		(1.03)		(1.17)		(0.49)		(0.82)	
exontherun × *age*	−12.150		6.6885		17.0723	***	−14.8488		−5.2043	**
	(−0.72)		(1.52)		(4.23)		(−1.61)		(−2.27)	
ctd	3.443		−0.3154		0.0668		0.0684		1.1089	
	(0.75)		(−0.30)		(0.07)		(0.04)		(1.22)	
Time FE	Yes		Yes		Yes		Yes		Yes	
Security FE	Yes		Yes		Yes		Yes		Yes	
R-Squared	0.3473		0.3897		0.3982		0.4422		0.3773	
Adjusted R-squared	0.2892		0.3728		0.3841		0.4291		0.3659	
F-Statistic	5.978		23.070		28.290		33.970		32.980	
Observations	2129		19083		18160		14034		30036	

Table 9. Central bank's purchase operations and their impact on order execution results

This table shows the means and two-sample t-test results for the initial and final GC–SC spreads. Panels A to C show the average GC–SC spreads at the time of order placement (in bps) and the rate concessions (in bps) until execution, cancellation, or market close, respectively. In each panel, the statistics for the securities that were not purchased by the central bank's operation (unpurchased bonds) are presented in the left-hand columns, and those for the securities that were purchased by the central bank's operation (purchased bonds) are presented in the middle columns. The "diff" and "test" columns show, respectively, the differences between unpurchased and purchased bonds and the significance of the Welch two-sample t-test, whose alternative hypothesis is that the true difference in means is not equal to zero. The GC–SC spread and rate concession are calculated from the bid orders placed after 12:20 p.m. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: Filled orders

	Initial GC–SC spread				Rate concession			
	Unpurchased	Purchased	Diff	Test	Unpurchased	Purchased	Diff	Test
CE-0	1.63	1.19	−0.44	***	0.15	0.13	−0.02	
QQE-I	2.57	2.16	−0.41	***	0.21	0.16	−0.05	**
QQE-II	3.71	4.10	0.38	**	0.35	0.46	0.11	***
NI	4.41	5.53	1.12	***	0.65	0.81	0.16	***
YCC-I	5.16	5.73	0.57	***	0.36	0.47	0.11	***

Panel B: Canceled orders

	Initial GC–SC spread				Rate concession			
	Unpurchased	Purchased	Diff	Test	Unpurchased	Purchased	Diff	Test
CE-0	1.92	1.40	−0.52	*	0.09	0.18	0.09	
QQE-I	2.68	2.27	−0.41	***	0.15	0.12	−0.03	**
QQE-II	3.54	3.75	0.21		0.20	0.31	0.11	**
NI	4.17	5.33	1.16	***	0.34	0.43	0.09	*
YCC-I	5.44	5.95	0.51	**	0.19	0.20	0.02	

Panel C: Unfilled orders

	Initial GC–SC spread				Rate concession			
	Unpurchased	Purchased	Diff	Test	Unpurchased	Purchased	Diff	Test
CE-0	3.06	NA	–	–	0.04	NA	–	–
QQE-I	5.75	5.86	0.11		0.42	0.49	0.07	
QQE-II	12.52	8.88	−3.64		1.43	0.92	−0.52	
NI	21.72	25.59	3.87		2.18	0.64	−1.54	***
YCC-I	21.53	20.78	−0.75		0.50	0.63	0.13	

Table 10. Impact of the central bank's purchase operations on the initial specialness
This table presents the results for the regression of the initial GC–SC spreads. The dependent variable is the GC–SC spread (in bps), and the regression equation is presented in Eq. (11). Security-level fixed effects and daily time dummies are not shown. The t-values are in parentheses and are calculated with cluster-robust standard errors. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	CE-0		QQE-I		QQE-II		NI		YCC-I	
holding	0.497		2.5319	***	20.7600	***	21.231	***	25.512	***
	(0.03)		(5.82)		(29.69)		(13.73)		(30.28)	
tradeda	−0.1835	**	0.0160		−0.0722	***	0.0875	**	0.1675	***
	(−2.04)		(0.92)		(−3.13)		(2.33)		(5.54)	
purchase	0.0314		−0.0229	*	0.0054		0.0726	**	−0.0456	
	(0.40)		(−1.89)		(0.29)		(2.40)		(−1.63)	
ontherun	2.0437	**	0.4297	**	1.6910	***	0.1654		6.6840	***
	(2.12)		(2.17)		(5.79)		(0.25)		(19.59)	
exontherun	5.09	***	1.0006	***	2.002	***	6.203	***	7.041	***
	(4.95)		(5.60)		(7.38)		(9.71)		(22.33)	
age	7.947		5.833	***	14.450	***	17.769	***	34.8488	***
	(1.29)		(7.08)		(13.38)		(5.00)		(19.15)	
ontherun × *age*	−0.026		26.2973	***	40.660	***	40.683	***	6.6023	***
	(0.00)		(10.93)		(14.10)		(7.39)		(4.17)	
exontherun × *age*	−16.893	***	3.0677	***	4.3370	***	−19.7220	***	−6.8372	***
	(−4.44)		(4.46)		(4.53)		(−8.23)		(−7.97)	
ctd	0.513		3.1221		1.4990	***	0.4388		8.6303	***
	(0.49)		(19.11)		(6.25)		(0.90)		(25.44)	
Time FE	Yes		Yes		Yes		Yes		Yes	
Security FE	Yes		Yes		Yes		Yes		Yes	
R-Squared	0.3584		0.6299		0.7362		0.6723		0.6333	
Adjusted R-squared	0.3013		0.6196		0.7300		0.6646		0.6265	
F-Statistic	6.277		61.480		119.300		87.920		93.970	
Observations	2129		19083		18160		14034		30036	

Table 11. Impact of the central bank's purchase operations on rate concessions
This table presents the results for the regression of changes in the SC rate until execution. The dependent variable is change in the SC rate until execution (in bps), and the regression equation is presented in Eq. (12). We test whether the central bank's purchase operation has an impact on the rate change between initial and final SC rate. Security-level fixed effects and daily time dummies are not shown. The t-values are in parentheses and are calculated with cluster-robust standard errors. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	CE-0		QQE-I		QQE-II		NI		YCC-I	
holding	−1.058		0.1115		0.4479	*	1.904	***	1.317	***
	(−0.55)		(1.12)		(1.90)		(2.61)		(6.88)	
tradeda	−0.0295	***	−0.0363	***	−0.0730	***	−0.1006	***	−0.1272	***
	(−2.63)		(−9.09)		(−9.38)		(−5.67)		(−18.50)	
mispricing	−0.0087	***	0.0022		−0.0177	***	−0.0348	***	0.0019	
	(−3.08)		(1.34)		(−6.97)		(−8.65)		(1.45)	
purchase	0.0011		0.0039		0.0104	*	−0.0068		0.0145	**
	(0.12)		(1.40)		(1.67)		(−0.48)		(2.28)	
ontherun	0.24	**	−0.1015	**	−0.044		−0.150		0.290	***
	(2.01)		(−2.24)		(−0.44)		(−0.48)		(3.74)	
exontherun	0.142		−0.076	*	−0.150		−0.059		0.2581	***
	(1.11)		(−1.86)		(−1.64)		(−0.20)		(3.60)	
age	0.204		0.6847	***	−0.704	*	14.280	***	0.6955	*
	(0.27)		(3.63)		(−1.93)		(8.52)		(1.68)	
ontherun × *age*	−0.277		1.9600	***	1.1427		−3.3760		−0.5529	
	(−0.26)		(3.56)		(1.17)		(−1.30)		(−1.54)	
exontherun × *age*	−0.156		0.2019	**	1.0124	***	0.2262		−0.3943	**
	(−0.33)		(1.28)		(3.13)		(0.20)		(−2.02)	
Time FE	Yes		Yes		Yes		Yes		Yes	
Security FE	Yes		Yes		Yes		Yes		Yes	
R-Squared	0.2456		0.2331		0.3592		0.2313		0.1902	
Adjusted R-squared	0.1781		0.2118		0.3441		0.2133		0.1753	
F-statistic	3.635		10.960		23.910		12.850		12.760	
Observations	2129		19083		18160		14034		30036	

Table 12. Impact of the central bank's lending facility on rate concession

This table presents the results for the regression investigating the impact of the central bank's lending facility on rate concession. The dependent variable is the change in the SC rate until execution (in bps), and the regression equation is presented in Eq. (13). We test whether the central bank's lending facility mitigates the impact on the rate change between initial and final SC rate. Original maturity-level fixed effects and daily time dummies are not shown. The results are reported for NI and YCC-I periods and for the two distinct subperiods of NI: 1st, from January 29, 2016 to April 30, 2016; 2nd, from May 1, 2016 to September 20, 2016. The t-values are in parentheses and are calculated with cluster-robust standard errors. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	NI		NI (1st)		NI (2nd)		YCC-I	
intercept	3.223	***	3.1202	***	1.9873	***	0.7964	***
	(11.36)		(7.92)		(7.77)		(4.63)	
holding	1.0355	***	0.8359	***	1.0892	***	0.6564	***
	(7.40)		(3.33)		(6.95)		(10.24)	
tradeda	−0.0885	***	−0.0891	***	−0.0879	***	−0.1276	***
	(−5.56)		(−3.15)		(−4.95)		(−19.32)	
purchase	−0.0150		−0.0184		0.0029		0.0138	**
	(−1.05)		(−0.76)		(0.17)		(2.19)	
$d_{-20 \leq sc < -10}$	−0.027		−0.2743	*	0.0992		0.0399	
	(−0.44)		(−1.89)		(1.63)		(1.29)	
$d_{-30 \leq sc < -20}$	0.192		−0.918	***	1.167	***	0.278	***
	(1.45)		(−3.88)		(7.59)		(5.90)	
$d_{-40 \leq sc < -30}$	0.275		−0.0384		0.3435		0.6850	***
	(1.38)		(−0.10)		(1.64)		(11.06)	
$d_{-50 \leq sc < -40}$	−0.397	*	−0.7291		−0.3025		0.6264	***
	(−1.68)		(−1.57)		(−1.22)		(9.92)	
$d_{-60 \leq sc < -50}$	−1.473	***	−0.2094		−2.9015	***	0.4791	***
	(−6.64)		(−0.56)		(−10.92)		(5.41)	
$d_{sc \leq -60}$	2.2116	***	19.4825	***	−1.3684	***	−0.5063	***
	(5.71)		(17.66)		(−3.60)		(−4.25)	
ontherun	0.1126		0.1134		−0.3066		0.2323	***
	(0.66)		(0.48)		(−1.09)		(4.15)	
exontherun	−0.2860		−0.4539		−0.1844		0.2735	***
	(−1.08)		(−0.92)		(−0.62)		(4.03)	
age	0.0635	***	0.0799	***	0.0571	***	0.0041	
	(6.16)		(4.56)		(4.83)		(0.68)	
ontherun × *age*	4.6084	**	3.9304		8.1618	**	−0.2643	
	(2.17)		(1.27)		(2.48)		(−0.97)	
exontherun × *age*	2.3347	**	3.2212		1.6890		−0.3886	**
	(2.12)		(1.44)		(1.40)		(−2.10)	
ctd	−0.1825		−0.2209		−0.1246		0.0404	
	(−0.93)		(−0.63)		(−0.57)		(0.55)	
Time-fixed	Yes		Yes		Yes		Yes	
Marutity-fixed	Yes		Yes		Yes		Yes	
R squared	0.1184		0.1486		0.1503		0.1134	
Adjusted R squared	0.1071		0.1363		0.1383		0.1011	
F statistic	10.450		12.120		12.520		9.200	
Observations	14034		5778		8256		30036	