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Marianna Blix Grimaldi
Sveriges Riksbank
marianna.grimaldi@riksbank.se

Fabienne Schneider
Financial Markets Department
Bank of Canada
fschneider@bank-banque-canada.ca

David Vestin
Sveriges Riksbank
david.vestin@riksbank.se

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The Usage of Security Lending Facilities under Unconventional Monetary Policy: Evidence from Sweden*

Marianna Blix Grimaldi† Fabienne Schneider‡ David Vestin§

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Abstract

This paper examines the interaction between quantitative easing (QE) and the securities lending facility (SLF) using a detailed dataset on Riksbank QE purchases, Swedish DMO SLF transactions and OTC repo deals. A theoretical model further shows how excess demand for assets and search frictions shift the SLF from a backstop to a first-resort tool. Empirically and theoretically, we find that QE expansion is closely linked to higher SLF use. Narrowing spreads between SLF yields and market repo rates make the SLF yield a floor for secured lending, weakening ties to monetary policy benchmarks and potentially altering its transmission. QE announcements also increase SLF usage, raising moral hazard concerns. Theoretically, QE strengthens cash-borrowing dealers' bargaining position and may reduce reliance on the repo market, with implications for market liquidity.

Keywords: Security Lending Facilities, Quantitative Easing, Repo Market
JEL codes: E52, E58, G21

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†Sveriges Riksbank, e-mail: marianna.grimaldi@riksbank.se
‡Bank of Canada, e-mail: fschneider@bank-banque-canada.ca
§Sveriges Riksbank, e-mail: david.vestin@riksbank.se

1 Introduction

Central banks started using large-scale asset purchases (QE) during the financial crisis in 2008-2009. These policies had positive effects on market functioning and financial stability - for example, the MBS purchases by the FED are deemed to have been crucial to avoid a market collapse that would have rendered important credit institutions unable to roll their market-based funding. Studies have also found that the stance of monetary policy was made more expansionary through QE policies by substituting for lower policy rates, supporting the recovery, and leading to higher inflation. However, it is also understood that such policies significantly impaired market liquidity by reducing the availability of bonds that could be freely traded on the market in such a way that public authorities needed to use other tools in the form of Securities Lending Facilities (SLF) and in some instances, as in the case of the Federal Reserve, build up new ones.

Although these were important decisions made by the public authorities, the interaction between SLF and QE and its implications for broader market functioning and monetary policy have been hitherto overlooked in the literature. In this paper, we focus on the direct interplay between QE and the SLF.

The primary goal of an SLF is to help public authorities address potential government securities shortages by allowing primary dealers to temporarily borrow these securities. This powerful tool enables public authorities to support the smooth functioning of the government bond market while improving market liquidity and financial stability. Without such a facility, primary dealers may hesitate to engage in trades if they are uncertain about securing specific bonds, especially those that are hard to find (*scarce*) on the market. The SLF acts as a safeguard in such situations. It is designed primarily as a backstop, with pricing structured to discourage routine use under normal market conditions. Which public authority provides SLF differs, in some cases it is the public debt management offices (DMO), and in other cases it is the central bank. To our knowledge, no central bank has intended the SLF as a direct monetary policy tool. In addition, the facility managing authorities - DMO and central banks - have gone to a length to clarify that SLF are a backstop mechanism meant to smooth market functioning and not to substitute for private market activity.

Both QE and SLF have effects on the supply of government bonds. They may act as countervailing forces when the central bank is reducing the amount of government bonds in the hands of the private sector and at the same time the SLF is increasing it. However, on theoretical grounds, it is hard to pin down whether the SLF hinders the transmission of unconventional monetary policy. Advocates of the use of SLF in conjunction with QE argue that as QE policies work by lowering long-term interest rates and as a signal mechanism, it is only beneficial if the short-term interest rate markets are as little as possible influenced by the *scarcity effect* caused by QE purchases. However, the central bank may find it difficult to lower long-term interest rates when short-term interest rates are prevented to diminish as much because of the SLF countervailing supply of bonds, an issue that is further exacerbated when the SLF is offered only to a handful of market dealers that exert significant market power. Lastly, whether the influence of an SLF is generally beneficial to financial stability and monetary policy transmission remains an empirical question.

In this paper, we use confidential, highly granular transaction data from the Swedish SLF to investigate the factors driving the usage of an SLF and uncover market dynamics that can have implications for the effectiveness of such facilities as last resort mechanism and monetary policy transmission. As with any backstop, there exists a risk that a SLF is "gamed". Such a risk, which can be related to potential moral hazard behavior or the risk of encouraging an adverse behavior, can damage the general investor's confidence and the overall functioning of the government bond market. Fundamentally, moral hazard and adverse behavior can be associated with any tool that plays a lender-of-last-resort function, particularly if the tool is granted only to a small number of dealers, as is commonly the case for an SLF. Beyond moral hazard issues, the SLF tends to drive secured lending rates to disconnect from other money market benchmark rates, thus potentially impairing the smooth transmission of monetary policy.

In addition to its granularity, our data extend over a uniquely long time period covering more than two decades of data, from 2002 to (June) 2023. Another important feature of our data is that the Swedish SLF is managed by the DMO and it is completely separated from the central bank and therefore monetary policy decisions. This separation provides the ideal setup for studying the interaction between QE policies and SLF, a clear advantage when establishing causal links.

We match the SLF transaction data with primary dealers' reported OTC repo market transactions yields on a bond-by-bond basis in the Swedish repo market from 2010 to June 2023. For most financial institutions, the OTC repo market remains the main source of short-term deposits and funding but, due to opacity of the OTC market, it is usually difficult to get an understanding of the dynamics of such a market. Thus, we provide novel evidence of the spread between the SLF yield and the repo market yield for each bond purchased by the central bank in its QE program. This spread is different from the *specialness premium* often investigated in the literature, which is based on aggregate information on collateral type. We complete these data with repo market volumes data collected by the Riksbank, the central bank of Sweden, and provide new evidence on the evolution of primary dealers' net borrowing of government securities.

Our unique data covers both information on volumes and yields of the SLF transactions and repurchase agreement (repo) market yields on a bond-by-bond basis, which allows us to track for each bond (ISIN) the interaction between QE purchases, SLF transactions and the repo market dynamics. We use a panel approach to link volume usage of the SLF facility to the size and changes of the QE program. We find that in months where the QE portfolio increased there is a marked increased usage of the facility, roughly corresponding to half of the size of the purchase. The stock effect is smaller, but is still significant and leads to a lasting increase in the average usage of around 5-10 percent of cumulated purchases. A decrease in the spread between the repo market rate and the SLF yield increases the usage of the facility. We show that the SLF yield becomes the *de facto* floor of secured lending rates. We also provide novel evidence of a systematic and protracted *rolling* of repo contracts by primary dealers. This cumulated evidence points to an SLF being used as a first resort rather than the last resort mechanism that it is intended to be. We speculate that this may have long-term implications for market functioning and monetary policy effectiveness.

To further enhance our understanding of the empirical results, we complement our empirical analysis with a theoretical search model. We explain the conditions under which primary dealers access the SLF and analyze its interactions with the repo market and asset purchases under QE. The theoretical results match and explain our empirical observations.

Our theoretical results show that the SLF, modeled as a reverse repo facility, is used during periods of excess demand. In this situation, there are more primary dealers facing investor demand for assets than there are primary dealers willing to lend them. In such cases, assets that are scarce and difficult to find in the OTC repo market due to search frictions are obtained through the SLF. This explains, as empirically observed, why the reverse repo facility, i.e. the SLF, is used despite the potentially large penalty spread between the repo market rate and the reverse repo facility rate.

In line with our empirical results, we also show in a second step that QE increases the usage of the reverse repo facility, i.e. the SLF. Especially primary dealers, who previously preferred uncollateralised deposits because of their higher interest rate, start to use the SLF to sell the provided assets (the reverse repo's collateral) to the central bank. One implication of this result is that asset purchases by the central bank in combination with the availability of a SLF can lead to a build up of short positions in the market.[1] The potential financial stability risks associated with this are a matter for further discussion. We also show that reliance on the repo market may reduce. This can raise liquidity concerns. In addition, we illustrate how QE affects the repo market rate: primary dealers with the option to sell assets to the central bank improve their bargaining position due to the increased value of their collateral, thereby securing lower repo borrowing rates. Therefore, QE indirectly increases the power of cash borrowers in the repo market. Taken together, the results explain why, during QE, we empirically observe an increase in the usage of the

[1] Primary dealers borrow assets from the SLF only to sell them to the central bank. After selling, they are left short these assets.

SLF and a narrowing of the spread between the repo market rate and the SLF rate. We further show, consistent with the data, that QE drives the repo market rate to the floor, i.e. it equals the SLF rate, becoming fully decoupled from the central bank deposit (or policy) rate. This decoupling can disrupt the transmission of monetary policy.

The paper is organized as follows: Section 2 provides an overview of the existing related literature, Section 3 describes market structure and institutional settings, Section 4 describes empirical facts on the usage of the SLF over time and changes to its pricing, Section 5 describes the data and the estimation results, Section 6 presents the theoretical model and Section 7 concludes.

2 Literature review

The main contribution of this paper is to improve the understanding of security lending facilities as possible mechanisms to mitigate bond supply shortages, including those related to QE programs. Our paper builds on two strands of the literature: a strand that investigates the relationship between QE and short-term funding markets and a second strand analyzing the impact of central banks' facilities on money markets.

Among recent papers on short-term funding markets, Corradin and Maddaloni (2020) explore the impact of the central bank's asset purchases on the scarcity premiums in the repo market during the European sovereign debt crisis in 2011. Roh (2019) analyzes how the Eurosystem's QE purchases triggered substitution effects via a repo specialness channel. D'Amico et al. (2018) quantify the scarcity value of US Treasuries as collateral in the US repo market. Ballensiefen et al. (2023) analyze the cross-sectional dispersion of repo rates in Europe and Infante et al. (2020) in the United States.

A growing literature focuses on central bank's facilities. Arrata et al. (2020) study the effect of the ECB's QE purchases on euro area special repo rates and show that the SLF managed by the ECB mitigate the decline of special collateral repo rates. Ballensiefen et al. (2023) examine the effect of deposit facility access and collateral eligibility for the ECB's asset purchases on repo market segmentation. Infante et al. (2020) analyze the implication of the Fed's Reverse Repo Program (RRP)'s facility as a source of safe assets. Closely related to our paper, Tobe and Uno (2024) develop a search theoretical model to investigate the implications of asset purchases and asset lending of the Bank of Japan on the repo market. Previous empirical literature on asset lending by central banks includes Greppmair and Jank (2023) who analyze the use of the securities lending facility in the Eurosystem following a change in its pricing in 2020. Fleming and Garbade (2004) analyze settlement fails in the Treasury market and the supply of government securities by the Fed after 9/11. Fleming (2012) evaluated the Term Security Lending Facility (TSLF) introduced by the Fed in 2008 to promote liquidity in the financing markets for Treasuries and other collateral. Logan and Bindseil (2019) give an overview over the securities lending programmes by central banks.

Finally, our paper also relates to a growing literature on QE and market functioning. Among others, Pelizzon et al. (2018) highlight for the first time the spotlight effect that Bank of Japan asset purchases had on the market liquidity of government securities in the Japanese market. Katagiri et al. (2023) also focus on the case of Japan but on the exchange-traded fund (ETF) purchase program and the interplay with the stock lending market. Krishnamurthy and Vissing-Jorgensen (2011) and D'Amico et al. (2018) analyze the relation between market functioning and scarcity in sovereign bond markets. Schlepper et al. (2020) study the impact of the Eurosystem's QE program on market functioning drawing on intraday transaction-level data for German bonds. Pelizzon et al. (2025) document channels through which QE-induced scarcity caused otherwise identical assets in the European sovereign bond market to be valued differently. They show that securities lending, as initiated by the ECB in 2016, can improve the functioning of Treasury markets. Also motivated by the European case, Jappelli et al. (2024) develop a preferred-habitat theory of the yield curve. Their theory indicates that asset purchases create repo specialness, thereby strengthening their impact on the securities directly targeted while dampening their transmission to the rest of the yield curve. At the same time, securities lending reduces repo specialness, and an SLF helps to globally transmit the intended monetary policy effects of quantitative easing to long-term interest rates. Blix Grimaldi et al. (2021) show that Riksbank QE programs negatively affected liquidity and market functioning via a stock-flow effect. Erikson (2021) examines the impact of the Riksbank's government bond purchases between 2015 and 2017 on the government bond market. He finds that, even for short holding periods, interest rates in the government bond market fell relative to the policy rate and discusses the implications.

3 Market structure and institutional setting

3.1 Repo market

The repurchase agreement (repo) market is an important source of collateralized short-term funding and provides essential financing for financial institutions. Repos are a critical secured funding tool for banks, hedge funds, money market funds and brokers. They are also a tool for diversifying borrowing and risk.

Repo markets play a key role in government bond market liquidity and the transmission of monetary policy, providing a lever to control inflationary pressures and the money supply in the economy. These markets are generally large in size compared to the size of the economies and they have been growing over time (ICMA, 2022). In fact, repos have become the predominant form of short-term funding after the 2008-2010 global financial crisis (GFC). In the euro area, daily turnover in the secured segment has doubled from around 250 billion in 2007Q2 to around 500 billion in 2020Q2, while the daily turnover in the unsecured segment has decreased from around 170 billion to 20 billion EUR (ECB, 2018). The daily turnover in the US repo market is estimated to be around 4 trillion USD. Given the size of the repo markets and their key role, a malfunction can impact borrowing costs for governments and other financial players as well as hinder the ability of central banks to transmit monetary policy impulses effectively.

Repos are collateralized loans, where a cash borrower sells a security to a cash lender, with an agreement to buy it back after a set period of time at a set price. The repo lender is promised an interest rate and benefits from having access to the collateral during the repo transaction. Because lending through a repo exposes the buyer to lower credit and liquidity risks, repo market rates tend to be lower than unsecured money market rates. The degree of deviation from unsecured rates depends on the value of the collateral pledged. The most used form of collateral is government bonds. Repos can be backed by a specific government bond (“special repo" or SC repo) or any bond from a predefined basket (“general collateral" or GC repo). Repo contracts can be traded either through centralized e-platforms acting as centralized markets where repos are centrally cleared through clearinghouses or over-the-counter (OTC).

Most studies focus on the inter-dealer market and the centrally cleared repos whereas there is a paucity of studies on the OTC market due to data limitation and general opacity of the OTC segment. However, the OTC market is economically important. The vast majority of traders have no access to the inter-dealer market but rely on the intermediation of the few dealer banks to access the repo market. The OTC market is also large in size. According to ICMA survey (2022), European repo market participants reported bilateral repo trading to be about 55 percent of total repo market which is estimated to be around EUR 9.000 billion.

In Sweden, the repos are “sell-buy back" or “buy-sell back" deals and the ownership of the security is transferred. Since 2018, repo contracts can be cleared at Nasdaq for central counterparty clearing. However, as in larger markets, the repo market remains predominantly an OTC market. Repo rates are quoted as a spread versus the Riksbank’s policy rate. Participants in the Swedish repo market can be categorized into two groups. The first group is made of relatively few large repo dealer banks (primary dealers), which have access to the SLF facility and are also monetary counterparties of the Riksbank. These large bank-affiliated securities dealers are significant intermediaries in the repo market and their share of the repo market is more than 50 percent. The majority of repo market participants including non-dealer banks and non-bank financial institutions such as pension funds rely on dealer banks to access repo markets. Notably, the non-dealer banks and non-dealer financial institutions do not have direct access to the SLF but rely on dealer banks. In addition, non-dealer banks and non-dealer financial institutions tend to rely on relationships and use as intermediary only one dealer bank, a sign of market segmentation.

3.2 The Swedish DMO

The Swedish DMO (SNDO) is the central government's financial manager. As such, it establishes and implements a strategy for managing the public debt, raises the required amount of funding through issuing government securities on the primary market, pursues risk-adjusted cost objectives, and meets other public debt management goals, such as contributing to an efficient and liquid secondary market for government securities. Government securities are sold into the primary market through banks - primary dealers - acting as agents for the government debt manager. Primary dealers also act as market makers on the secondary market. In this role, they provide liquidity by continuously quoting bid and ask prices, facilitate trading of previously issued government securities, and make-markets by ensuring smooth functioning and price discovery.[2]

3.2.1 The Swedish DMO's SLF

As a way of contributing to an efficient and liquid secondary market for government securities, the Swedish DMO offers short-term loans of government securities - mainly bonds - in the form of repos to primary dealers, through a standing securities lending facility (SLF). The facility is intended as a backstop, supporting bond and repo market liquidity by providing a safety net: if dealers encounter a delivery problem or need to cover (or create) a position in the market and cannot meet their commitments, the Swedish DMO provides for the missing securities via a cash repo or a repo swap transaction. This supply of bonds occurs outside of the well-ahead scheduled issuance in the primary market. In practice, the SLF is intended to contribute to government bond market functioning by fine-tuning the supply of government bonds in the bond market, without unduly curtailing private repo market activity. In this function, by providing a safety net, the DMO acts as a "Securities Lender of Last Resort".

The Swedish DMO offers such market-supporting repos at different maturities: overnight (O/N), tomorrow-next (T/N) and one week (T/W). The O/N and T/N facilities are cash facilities, whereas the T/W is a repo swap facility where primary dealers can exchange government securities against government securities on a cash neutral basis. A large ma-

[2]Market-makers display indicative two-way prices on electronic information systems which is instantaneously relayed to market participants. The normal trading lot in Swedish government securities is SEK 200-500 million.

jority of repos (about 80 percent) are traded in the T/N facility, followed by the T/W swap facility (about 10 percent) and the O/N facility (about 5 percent).

The SLF is offered at a premium. As with any safety net, there is a risk that a SLF could be “gamed". This risk can be related to potential moral hazard behavior and speculative arbitrage, which can damage investors’ confidence and the overall functioning of the government bond market. A critical tool to ensure that the facility is used as a backstop is the pricing framework.[3]

The Swedish DMO pays an interest rate below the risk-free rate (monetary policy rate) on the amount of cash or securities that is exchanged in the facility. The premium paid on the borrowed amount is set as a fixed spread to the policy rate and ranges from 45 to 30 basis points, depending on the maturity of the repos. Primary dealers can borrow at the set premium any bond in unlimited size at O/N and T/N maturity against cash. In the repo swap facility, there is a maximum volume of SEK 2 billion per government security and primary dealer that can be transacted.[4] In addition, the facilities come with the option of rolling-over the transactions until one day prior to maturity of the securities.[5]

3.3 The Riksbank

According to Swedish law, the main objective of the central bank is to maintain low and stable inflation. The main tool of the Riksbank for implementing monetary policy is the policy rate. However, when the policy rate reached the effective lower bound in the aftermath of the GFC, similarly to other central banks, it adopted QE to further stimulate the economy and stabilize the inflation rate around the target. The Riksbank started the QE program in February 2015. Purchases of securities under the QE program continued up to April 2023 when the central bank started to reverse its policy by selling the securities that it had previously purchased.

[3] Another key condition is counterparty policy. In general terms, counterparty policy is influenced by the role that the facility is meant to play and the goal it aims to achieve. A broad range of counterparties provides the public authority with the ability to address broad-based liquidity strains. At the same time, having many counterparties is costly from a public manager’s perspective, as it has to manage a large number of counterparties and it may even crowd out private market activity. The Swedish DMO has five primary dealers.

[4] More specifically, repo swaps of government securities are traded in multiples of SEK 500 million and up to SEK 2 billion per government security and primary dealer.

[5] Newly issued nominal government bonds have special terms for 10 basis points below the Riksbank’s policy rate. These terms apply for no more than the volume that is equivalent to the difference between SEK 20 billion and the issued volume. The volume is evenly distributed between primary dealers. The rationale for offering more advantageous terms for newly issued bonds is to encourage primary dealers to build volumes in the market and by so doing promote liquidity for newly issued bonds.

3.3.1 The Riksbank's QE program

From February 2015 to April 2020, Riksbank significantly expanded its quantitative easing program by purchasing government bonds. Starting with an initial 10 billion SEK in February 2015, the total purchases grew to 200 billion SEK by mid-2016, equivalent to about 30 percent of the outstanding Swedish government bonds and 5 percent of Sweden's GDP at that time. The program continued to grow, reaching 275 billion SEK at the end of 2016 and 290 billion SEK in April 2017. In 2018, the focus shifted to reinvesting in matured bonds and coupons, totaling around 60 billion SEK. An additional 45 billion SEK was purchased in April 2019 to maintain market presence, bringing the total to 316 billion SEK. In response to the COVID-19 pandemic, Riksbank announced in March 2020 the purchase of up to 300 billion SEK in securities, including types other than government bonds, raising the total holdings to about 335 billion SEK.[6]

The Riksbank conducted these government bond purchases exclusively on the secondary market through weekly auctions with its monetary policy counterparties.[7] The Riksbank was transparent in its communication of the auction details. It clearly stated the specific bond that it would purchase and the target amount as well as the range within which it was to eventually deviate from the target. The time and days were clearly detailed in the announcement, as well as how long the auction procedure would last. Figure 1 provides an example of an auction announcement from the Riksbank. In the example below, the Riksbank announced on September 30, 2022, that it would buy 0.3 billion worth each of the government bonds 1060 and 1056, at an auction held on the 7 of October, 2022. Thus, market participants had about a week to prepare for which bids to submit.

[6] In our analysis we include exclusively nominal government bonds.
[7] The monetary policy counterparties include the primary dealers of the DMO.

SPECIAL TERMS AND CONDITIONS FOR THE RIKSBANK'S PURCHASES OF BONDS VIA BID PROCEDURE

Bid procedure, 2022-10-07	
Bonds	SWEDISH GOVERNMENT: 1060. SE0009496367. 2028-05-12 SWEDISH GOVERNMENT: 1056, SE0004517290, 2032-06-01
Bid date	2022-10-07
Bid times	09.00-10.00 (CET/CEST) on the Bid date
Requested volume (corresponding nominal amount)	1060: 300 mln SEK +/-150 mln SEK 1056: 300 mln SEK +/-150 mln SEK
Highest permitted bid volume (corresponding nominal amount)	1060: 300 mln SEK per bid 1056: 300 mln SEK per bid
Lowest permitted bid volume (corresponding nominal amount)	SEK 10 million per bid
Expected allocation time	Not later than 10.15 (CET/CEST) on the Bid date
Delivery and payment date	2022-10-11
Delivery of bonds	To the Riksbank's account in Euroclear Sweden AB's securities settlement system 1 4948 6383

Stockholm, 2022-09-30

Figure 1: Riksbank's auction announcement

4 Swedish SLF usage over time

The key feature of a SLF is that its availability strengthens investors' confidence in the continued liquidity and functioning of the market. In this way, the DMO's SLF plays a critical role in maintaining and improving the liquidity of government bonds. Because of this critical role, usage of the SLF is associated with episodes in which single government bonds are difficult to obtain and when government bond market liquidity could be generally low. Dealers resort to the facility to overcome that scarcity of government bonds on the market. Thus, the usage of the facility strongly correlates to how well the government bond and the repo market for government securities function. Figure 2 shows the evolution of the total volume of the SLF over time, from early 2002 to the end of our sample in June 2023.

Figure 2, as expected, shows that the usage of the facility increases at times of increased strain on financial markets, as was the case during the 2008-2009 global financial crisis (GFC) and the ensuing European Sovereign Debt Crisis (2009-2012). From February 2015 to the end of our sample period - June 2023, volumes traded in the SLF have been substan-

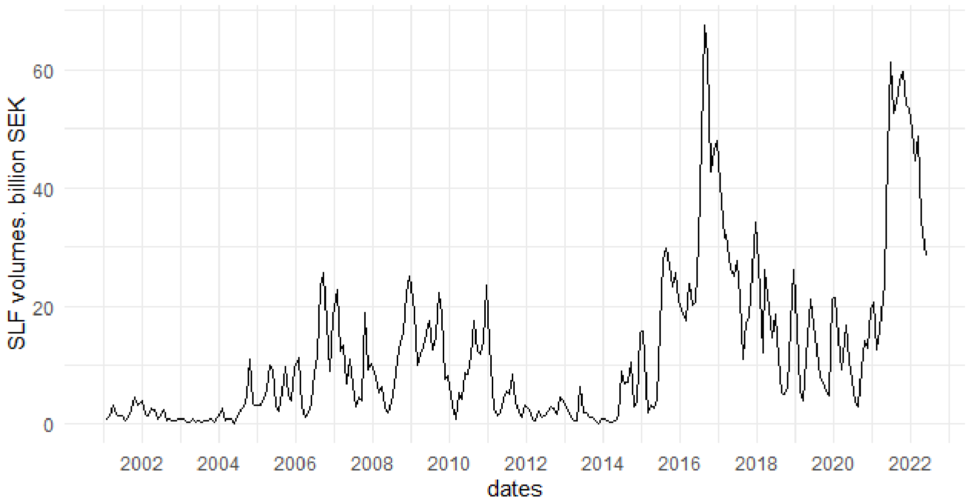

Figure 2: SLF volume

Note: The black line represents the total SLF volumes in billion SEK, monthly averages.

tially high on a daily basis, averaging about 30 billion SEK in daily transactions over the period. To put things in perspective, during the last two decades, the issuance of nominal government bonds in the primary market has averaged about 60 billion SEK *per year*. In addition, the usage of the SLF is much more volatile during the QE period than during the previous period. The spike in 2018 corresponds to a period in which Riksbank purchases of new bonds peaked, whereas the spike in June 2022 corresponds to a period in which market liquidity deteriorated sensibly and the swap facility yield was changed, making the access to the facility less onerous. We come back in a later section to this change in SLF pricing.

4.1 QE-induced bond scarcity

QE-related purchases of nominal government bonds were initiated in February 2015 and cumulated during the first couple of years to reach a Riksbank holding of around 50 percent of the total outstanding stock. As a result, after the start of QE, bond scarcity increased as the free-float - the amount available to the financial market to trade - contracted significantly and relatively fast. The Riksbank reinvested maturing debt and coupons such that it maintained ownership of around 50 percent up until the increase in purchases during the Covid-19 period.

With diminishing free-float, the QE-induced government bond scarcity affected the government bond market functioning by having a significant impact on market liquidity (Blix Grimaldi et al., 2021). The continued pressure from the demand of the central bank made scarce bonds trade at a specialness premium in the repo market, such that the party exchanging liquidity for a bond was willing to receive a lower interest rate.

At the same time, the central bank purchased the bonds in the secondary government bond market at a premium (Laséen, 2023), and, by so doing, increasing the profitability of short-sellers. Once dealers shorted the bonds, they needed to roll-over the repo contract until they were able to cover their position either by buying the bond in the cash market or remaining structurally short by continuing rolling over the bonds. Structural rollover is possible only if bonds can be obtained in a sufficient amount continuously either from the market or through a SLF.

4.1.1 The SLF mitigated bond scarcity

The SLF mitigated the decrease in the free-float. Figure 3 shows the evolution of the bond amount the primary dealer sourced from the SLF in terms of bond outstanding amount (left panel) and in terms of Riksbank's holding (right panel). In terms of bond outstanding amount, the primary dealers obtained an average share of bond amount that was about 4 percent over the period from the QE start to the end of our sample. By comparison, this is a significantly higher share than that found for example by Inhoffen and van Lelyveld (2023) for the Eurosystem of 1 percent, in February 2020. In terms of Riksbank's holding, the primary dealers obtained a bond amount of about 10 percent (Figure 3 right panel).

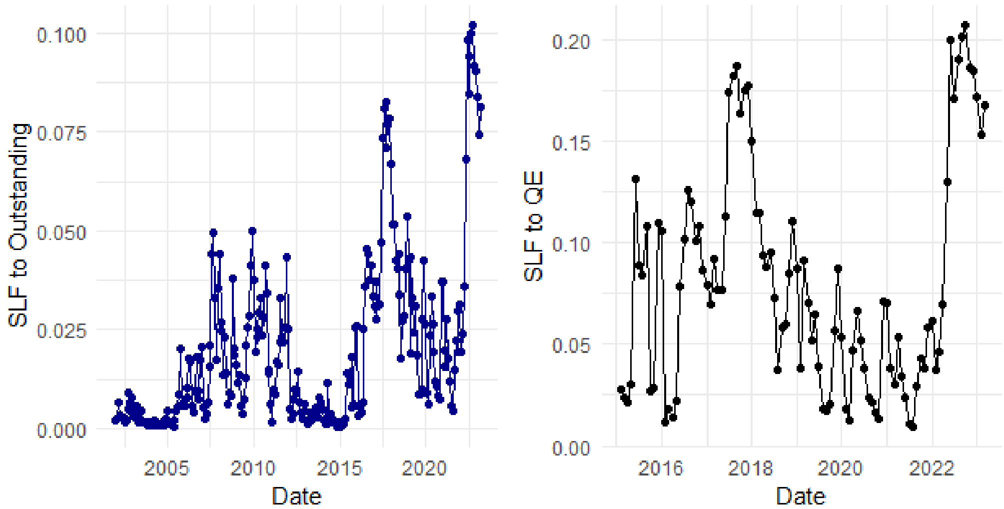

Figure 3: SLF volumes in terms on outstanding bond amount and Riksbank holding

This strong supply of bonds through the SLF may in part be explained by the fact that the DMO allows primary dealers to roll over their transactions in the SLF until one day before the maturity of the bond. In the repo market, rolling over is a common practice that may or may not coincide with collateral re-use. Dealers use collateral intermediation as a vehicle to source liquidity and making a profit by matching reverse repo and repo quotes with a positive repo rate spread. Our analysis documents rolling behavior for the SLF. To our knowledge, this evidence is the first of its kind.

4.2 Rolling over

For each bond in our sample, we compute a conservative measure of rollover as the number of consecutive days that each bond has been traded. In addition, of those bonds that were traded in consecutive days, we only select those whose traded amount diverged less than 1 percent from the previous day. The amount rolled is computed for each bond and the primary dealer, distinguishing by the type of facility, i.e. if the bond was rolled over in the two cash facilities - O/N and T/N - or in the repo swap facility.[8]

Importantly, based on the full sample of bonds traded in the SLF, our results show that rolling over in the SLF was not new in the period before QE. However, it happened relatively rarely and in relatively small amount, whereas it increased significantly after the start of QE. The number of days bonds were rolled before QE was 928. After QE started in February 2015, the number of days more than doubles and reaches 2372. In addition, after 2015 each bond was rolled for longer clustered periods.

In Figure 4 we show the *rollover ratio*. We compute the rollover ratio as the total monthly amount that was rolled over scaled by the overall monthly amount that was traded in the SLF. A battery of t-test confirms that the difference between the pre-QE and post-QE rolled-over amount is statistically significant for the SLF as a whole, the individual O/N and T/N facilities and the repo swap facility as well as, notably, for individual primary dealers.

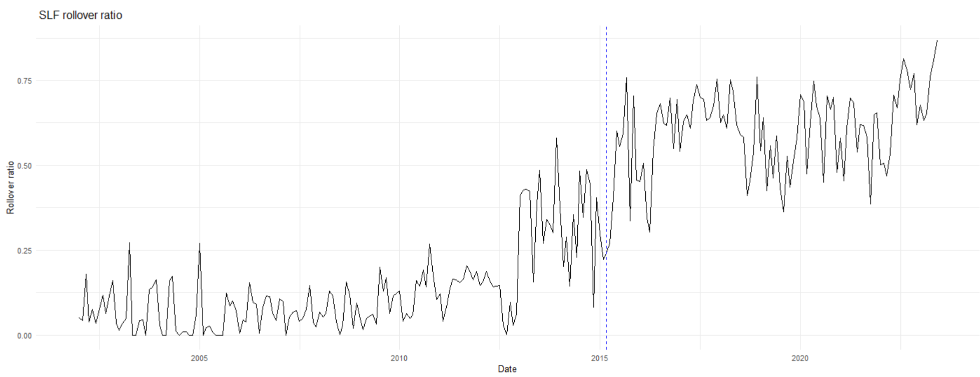

Figure 4: SLF rollover ratio

Note: The rollover ratio is computed as the total monthly rolled over amount scaled by the overall monthly amount traded in the SLF. The vertical dashed line marks the start of the QE program.

[8]In the repo swap facility government securities are traded in one-week repos. To take this into account, we have adjusted our rolling measure based on consecutive weeks rather than days.

In addition, rolling was carried out by all primary dealers, although the extent varied considerably. Some dealers consistently rolled over significantly larger amounts than others, especially after the introduction of quantitative easing (QE) in February 2015. Due to the sensitive nature of the data, we are limited to presenting variation at a highly aggregated level. One such approach is to use a ranking measure which indicates each primary dealer's relative position in an ordered series based on the amount rolled over.

In Table 1 we present the average rank of primary dealers, calculated from monthly aggregated volumes in the T/N facility whereas Table 2 reports summary statistics of the monthly average amounts rolled over in the T/N facility, averaged across primary dealers, for the periods before and after the introduction of QE in 2015.[9] As shown in Table 2, not only the average amount rolled over increased, but also the variation in the amount rolled raised significantly after the start of QE. The combined results of Table 1 and 2 point to a general increase in rolling behavior and to significant differences of individual primary dealers in accessing the SLF.

Table 1: Average rank by rolled over amount

	rank rolled amount
A	2.04
B	2.78
C	3.28
D	3.46
E	3.52
F	3.65
G	3.87
H	4.12
I	4.77

Table 2: Summary Statistics Pre- and Post 2015 (QE)

	Mean	Stdev	Min	Max	Range
Pre-QE	5.90	4.90	1.66	15.76	14.10
Post-QE	19.16	9.68	4.37	26.80	22.44

Note: The values in the table are summary statistics for the volumes rolled over in the T/N facility averaged across primary dealers. Values are in billion SEK.

4.3 SLF pricing

The yield charged to the primary dealers to access the SLF is one of the key strings attached to the use of the facility. It is intended to be large enough to minimize the risk of

[9]The ranking reflects each dealer's position in the monthly distribution of rolled-over amounts, sorted in ascending order. The T/N facility accounts for 80-90 percent of the total SLF volume.

moral hazard and overuse of the facility. However, it should not be prohibitively high to discourage the use of the facility when it is needed.

From a primary dealer's perspective, the SLF yield is the opportunity cost of using the facility. It is the higher cost of resorting to the facility when primary dealers may have more favorable conditions on the repo market but cannot access it frictionlessly. The more expensive the facility, the less likely the primary dealer will use it. This opportunity cost that the dealer faces depends on the SLF yield decided by the public authority as well as the wider repo market conditions.

The Swedish DMO sets the SLF yield at a fixed premium to the monetary policy rate. The premium is 45 basis points for the O/N facility, 40 basis points for the T/N one, and 30 basis points for the repo swap facility. During our sample, the SLF yield was changed for a few periods on a temporary basis. More specifically, in December 2019, the yield on the swap facility was lowered through a change in the premium by 10 basis points to 20 basis points. In addition, the volume limit was lifted to 4 billion SEK from 2 billion SEK per government bond and primary dealer. The yield on the two cash facilities - O/N and T/N - was left unchanged. The decision on the repo swap facility yield was reversed in August 2021 whereas the limit was kept in place until September 2022. In June 2022, the yield of the repo swap facility was again set to 20 basis points below the Riksbank policy rate. The higher limit was to be kept in place until May 2023. In April 2023, it was decided to keep in place both the lower yield and the higher volume limit on the repo swap facility.

Since both fixed premium and policy rates change relatively infrequently, the SLF yield will also adjust less often than the repo market rate. As a result, the cost of accessing the facility will fluctuate depending on the SLF yield relative to the prevailing repo market interest rate. The repo market rate is driven by repo market supply and demand dynamics which include, among other factors, bank funding strategies, financing decisions of leveraged investors, and the hedging practices of bond investors as well as regulatory constraints.

To gain additional insight into our mechanism, we have computed the spread between the SLF yield and the bilateral OTC repo market rate. We source the private repo market rates from the proprietary repo book data of a primary dealer in Sweden. Figure 5 shows the evolution of this spread over time and the usage of the SLF during the same period, 2010-2020. It suggests an inverse relationship between the spread and the use of the facility. At times when the SLF yield is close to the interest rate that prevails in the repo market, it is reasonable that primary dealers have a strong incentive to use the risk-free and on-demand SLF instead of searching and matching bonds in the repo market even when bonds may be available.

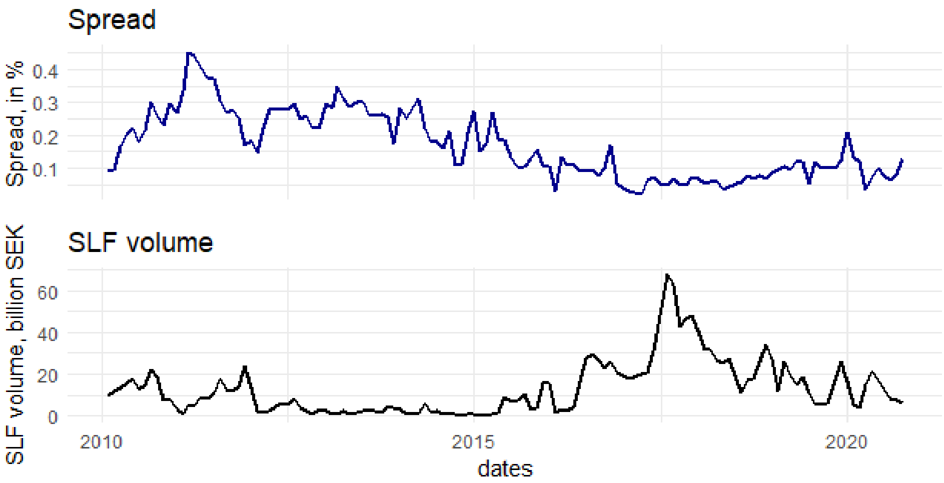

Figure 5: SLF volume and spread

Note: The blue continuous line in the upper panel illustrates the difference in percentages between the SLF yield and the prevailing repo market rate. In the lower panel, the black line represents the SLF volumes in billion SEK. Both variables are monthly averages.

4.4 Monetary policy interest rates and SLF yield

The importance of the SLF pricing can also be seen in relation to the monetary policy interest rates. The period from 2015 to the end of our sample coincided with very low policy rates and a compression of the money market rates. Most of the money market rates adjusted to the central bank's deposit facility rate, which provides an anchor for short-term interest rates. More specifically, the deposit facility rate provides a lower bound for interest rates and opens a channel for monetary policy to affect the yield curve through expectations of changes in the deposit facility rate. The more restrictive the lower bound, the more effective a decrease in the deposit facility rate is in lowering both short- and long-term interest rates. We find that unsecured money market rates adjusted to the policy rate. However, repo market rates instead adjusted to the SLF yield. We note that the deposit rate is only avaliable to the (currently 26) monetary policy counterparties, whereas the private repo-market is widely accessible to most financial institutions - though the market is OTC and essentially functions through a limited number of large banks. The SLF yield had a floor effect on repo-market lending rates, with the floor level being determined by the SLF pricing settings.

Between 2019 and 2022, the Riksbank gradually changed its monetary policy framework, resulting in a narrower corridor where lending and deposit facility rates were set 10 basis points above and below the policy rate, respectively. However, as shown in Figure 6, even in this new framework, repo market rates continued to remain away from the deposit facility rate and remained anchored to the SLF yield, confirming that SLF yield rather than the interest rate corridor of the Riksbank's operational framework affects repo transactions with government bonds as underlying collateral during the QE period. In other words, secured lending rates disconnected from other money market benchmark rates. [10]

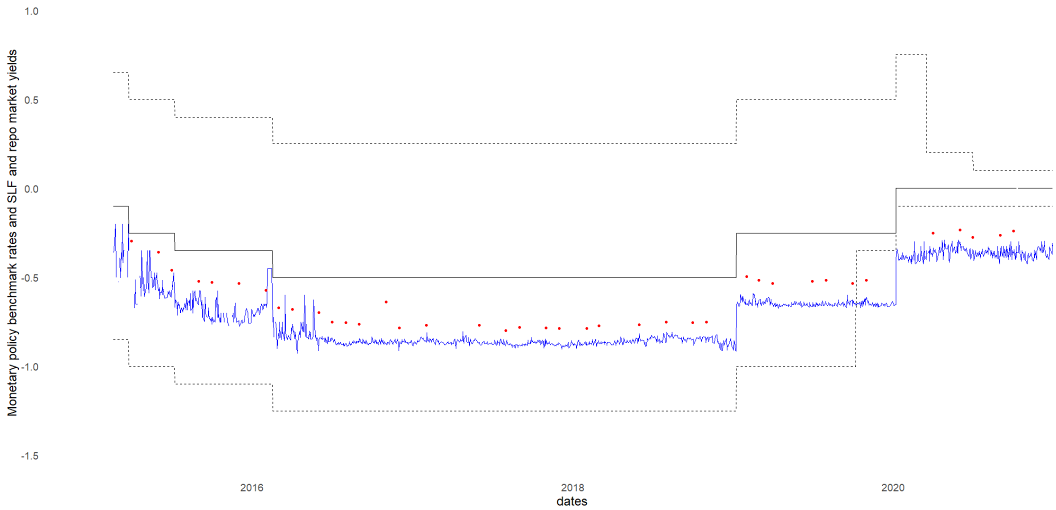

Figure 6: SLF yield and monetary policy rates

Note: The blue continuous line is the SLF yield and the red dots denote the repo market rate. The black continuous line represents the monetary policy rate and the black dotted lines the Riksbank deposit (lower line) and lending (upper line) facility rates. all rates are in percentages.

5 Data and estimation procedure

5.1 Hypotheses Development

Our regression analysis in this section is motivated by several hypotheses. Although these hypotheses are derived from the results of the theoretical part presented in Section 6, we present them here to guide the empirical analysis.

Our model results described in the theoretical part show that primary dealers may access the SLF even when the SLF rate lies below the repo market rate. They do so because finding the required securities in the repo market might in practice be more expensive due to OTC search frictions. This scarcity effect strengthens as excess demand for the assets increases: the higher the excess demand, the greater the SLF usage. This mechanism is consistent with the evidence in Figure 5, which shows positive SLF volumes despite a

[10]This is corroborated by Hansson and Wallin Johansson (2023). Based on granular, highly confidential data that Riksbank collects on completed repo transactions, they find that between 2019-2022 interest rates for repo transactions with government bonds as underlying collateral deviate significantly from the policy rate.

positive spread between the repo market rate and the SLF rate. Moreover, QE amplifies this effect by increasing the attractiveness of these assets to a broader set of market participants, thereby reducing reliance on the repo market and further increasing the use of the SLF. This leads us to our first hypothesis.

Hypothesis I: *QE purchases increase SLF usage.*

This hypothesis is also supported by Figure 3, which illustrates the increased reliance on the facility during QE.

In addition, our model described later reveals that during QE the spread between the repo market rate and the SLF rate is compressed. The repo market rate falls to the floor, i.e. it equals the SLF rate. The repo market rate fully decouples from the policy rate. At the same time SLF usage is elevated. Figure 5 and Figure 6 document this floor effect. This effect was discussed in Erikson (2021). The lower bound can be derived as a simple arbitrage where a primary dealer extracts bonds from the SLF and does a repo transaction in the private market exchanging bonds for cash. We take the following hypothesis:

Hypothesis II: *During QE (compared to without), the spread between the repo market rate and the SLF rate is compressed while SLF usage is higher. Said differently, there is a negative correlation between the spread and SLF usage.*

Those first two hypotheses directly relate to our Baseline Analysis in Section 5.3.1. We regress facility usage on QE purchases and the premium as well as the interaction between the two. Additionally we also measure the impact of scarcity by including QE holdings.

In a second regression, we examine announcement effects, motivated by the following hypothesis derived from the model results:

Hypothesis III: *Some primary dealers use the reverse repo facility during QE to borrow assets with the purpose of selling them to the central bank (either for their own accounts or on order from clients).*

For the third and final regression (next to robustness checks), we do not formally derive a hypothesis. This regression documents substitution effects between facilities when their relative pricing changes. It would be straightforward to extend the model to include two facilities instead of one, and show that agents adjust their relative usage in response to changes in relative prices.

5.2 Data

We collect data from different sources and with different levels of granularity and confidentiality. The primary data are unique and highly confidential data provided by the DMO. This highly granular dataset collects all SLF transactions between the DMO and the primary dealers. The data are at the transaction level and cover the period from January 2002 to June 2023. For each SLF transaction, we observe the trade and settlement dates, the nominal amount, the yield paid by each primary dealer for each bond, the masked identity of each primary dealer, the collateral used (at ISIN-level) and the maturity of the collateral. The outstanding volume of each bond as well as bond-by-bond issuance (including switches) are also provided by the DMO.

From the Riksbank's publicly available data we obtain information on a bond-by-bond basis about government bond purchases under its QE program. For each bond, we obtain the amount purchased at each date and the central bank's holdings of each bond. Holdings are the cumulated purchased volumes of the bonds. From the Riksbank we also obtain confidential data on daily volumes traded in the repo market that are backed by Swedish government bonds as collateral. From this source, we obtain information about repo transactions volumes both in the inter-dealer as well as the wider OTC market. For each day, we observe the identity of the dealer involved in the transaction, her counterparties, and the direction of the trade, i.e. if it was a collateralized borrowing or a lending of the cash. This dataset covers the period from January 2002 to June 2023.

We complement the information from the Riksbank on the repo market with data on repo market yields obtained on a bond-by-bond basis, weekly averaged from the repo book of a large private dealer operating in Sweden. This dataset covers the period 2010-2020.

Finally, from the Financial Supervisory Authority, we obtain a Swedish government bond market liquidity indicator. All other data are retrieved from commercial data providers.

In our analysis, we include only nominal bonds as most of the volumes issued on the primary market and subsequently traded in the SLF as well as on the secondary market are in nominal bonds. For each bond in the SLF, we compute the total daily volume as the sum of the volume traded by individual dealers on that day in O/N, T/N and repo swap transactions. We compute the average daily SLF premium paid on each bond as the average difference between the yield paid on each bond by each dealer and the monetary policy rate. We match these daily data on a bond-by-bond basis to the dataset built from the Riksbank's QE program, the repo market volumes, and the data from the private market actor. We scaled all volume variables in our dataset by outstanding bond volumes. After cleaning the raw data and making necessary transformations and matching, we arrive at a final dataset of 57562 daily observations. We aggregated the data to a weekly frequency to mitigate noise in the daily, transaction-based data. Our data consists of a total of 3073 weekly observations. We have 15 nominal government bonds. Table 1 in Appendix 1 shows key descriptive statistics of the main variables we use in our empirical exercises. The time period is January 2002-June 2023.

5.3 Estimation results

5.3.1 Baseline analysis

To quantify the effect of different factors on SLF volumes, we estimate a panel regression with fixed effects as in the following equation (1):

$$\begin{aligned} SLF_{i,t} = \alpha_i + \gamma_t + \beta_1 Holdings_{i,t-1} + \beta_2 Purchases_{i,t} + \\ \beta_3 Premium_{i,t} + \beta_4 Premium_{i,t} * Purchases_{i,t} + \beta_5 X_{i,t} + \epsilon_{i,t}. \end{aligned} \tag{1}$$

where $SLF_{i,t}$ is the volume of the SLF for each bond i in a given week t. As a share of outstanding, $Holdings_{i,t-1}$ denotes the lagged Riksbank holdings as a share of outstanding volumes, $Purchases_{i,t}$ are bond purchases by the Riksbank as a share of outstanding volumes, and $Premium_{i,t}$ denotes the premium on each bond. The term $Premium_{i,t} * Purchases_{i,t}$ captures the possible nonlinearities associated with the interaction between the SLF premium and the Riksbank's purchases, allowing the (marginal) effect of the Riksbank's purchases on SLF volumes to vary with $Premium_{i,t}$. In the baseline specification, as $Premium_{i,t}$ we use the SLF premium on a bond-by-bond basis, i.e. the difference between the SLF yield and the policy rate. In a second specification, as alternative to the SLF premium, we use the spread between the SLF yield and the repo market yield from the repo book of a large dealer.

The vector $X_{i,t}$ includes a set of one period lagged control variables such as bond issuance in the primary market and repo market activity.[11] New bond issuance increases bond supply and therefore lowers the potential bond scarcity that primary dealers (and investors) may face when there is not enough free-float, i.e. when the supply of bonds that are free to trade is low. Thus, for each bond i at each time t, an increase in the issuance of bonds in the primary markets - $Issuance$ - is expected to reduce the use of SLF in the next period. To take into account possibly delayed effect of bond issued on primary markets we take one lag of the variable in the baseline specification.

The repo market activity is defined as the net collateralized lending of cash in the repo market with government bonds as collateral and is expected to be positively associated with the volumes of SLF. An increase in the demand of government bonds in the secondary market, by, for example, pension funds, increases government bond demand - i.e. collateralized lending of the cash - in the repo market. If higher demand cannot be accommodated on the repo market, the usage of SLF tends to increase *ceteris paribus*. Similarly, if government bond demand decreases in the secondary market, we should observe a decline in

[11] In baseline specification we choose one period lag, but results are robust to choosing different lags specifications.

SLF volumes. To further shed light on the repo market demand for government bonds, we distinguish, for each time t, between the demand for government bonds by primary dealers towards all repo market participants including primary dealers as reported in the Riksbank's SELMA database - *Repo mrkt all*, and the demand for government bonds by primary dealers towards other primary dealers. We call this variable *Repo mrkt rep.* To take into account possible delayed effect and address potential reverse causality effect, we take the variable at one period lag in the baseline specification.

Finally, we include time and bond fixed effects in our baseline specification as to capture all effects that are specific to time periods (panel units) but constant for panel units (time periods). These effects include, for example, changes in regulation and financial conditions. To account for the possibility that error terms may be correlated, we adjust the standard error for cross-sectional as well as serial correlation, i.e. we use Arellano robust standard errors.

Table 3 summarizes our main results.[12]

The central bank QE program significantly affects the total volumes of the SLF in all specifications. Both purchases and holdings increase the usage of the repo facility. The positive impact of Riksbank's purchases derives from the action of bond sellers who sell securities to the central bank and exchange them for cash. Primary dealers put pressure on the SLF by sourcing the bonds for their customers as well as themselves. $RBHold$ measure scarcity on the bond market. As Riksbank's holdings increase and scarcity becomes more acute, the SLF usage tends to increase. Although the coefficient of $RBPurch$ is greater than that of $RBHold$, the economic significance of holdings tends to be greater than than of purchases, as purchases are one-off events, whereas the central bank's holdings continually grow with new purchases and have lasting effects. This result is similar to that discussed in Blix Grimaldi et al. (2024), documenting the differential impact of central bank purchases and holdings on government bond market liquidity.

[12] As part of our robustness checks, we include Vol_t among the regressors in the vector $X_{i,t}$ when appropriate. The variable Vol_t is intended to capture the influence of overall economic conditions. The effect of deteriorating economic conditions on SLF usage is *a priori* ambiguous, as it depends on whether flight-to-quality or flight-to-liquidity concerns dominate in the government bond market. In the baseline specification, Vol_t is measured using the MOVE index; as an alternative, we employ the government bond market liquidity indicator provided by the Financial Supervisory Authority.
To address non-normal residuals arising from the skewed distribution of the dependent variable which only takes positive values we apply a logarithmic transformation and estimate the model in log levels.
We further assess robustness across different data frequencies, using both higher-frequency (daily) and lower frequency (monthly) data instead of weekly observations.
Moreover, we compute a weighted version of the premium by weighting it according to volumes in the underlying facilities (O/N, T/N, and repo swap).
We also vary the number of lags for variables included in $X_{i,t}$, use individual fixed effects instead of twoways fixed effects, and employ cross-sectional robust standard errors rather than Arellano robust standard errors. We report the robustness checks tables in Appendix I.

Overall, the results of these robustness checks are qualitatively similar to those of our baseline model.

Table 3: Regression results, baseline model

	Dependent variable:					
	SLF Volumes					
	(1)	(2)	(3)	(4)	(5)	(6)
RB Hold	0.03**	0.07***	0.07***	0.07***	0.08***	0.07***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
RB purch	0.62***	0.54***	1.69**	1.68**	1.70***	1.68**
	(0.16)	(0.14)	(0.67)	(0.67)	(0.63)	(0.67)
SLF Premium		0.23***	0.20***	0.20***	0.16***	0.20***
		(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Interaction			3.44**	3.44**	3.47**	3.44**
			(1.73)	(1.73)	(1.63)	(1.74)
Issuance				−0.07	−0.06	−0.07
				(0.23)	(0.25)	(0.23)
Repo Mrkt Rep					0.01**	
					(0.01)	
Repo Mrkt All						−0.0000
						(0.001)
Twoways fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Clustered error	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,187	3,073	3,073	3,073	3,073	3,073
R^2	0.01	0.06	0.06	0.06	0.07	0.06

Note: The table shows twoways fixed effect panel regression results of the baseline model as in equation 1 with data aggregated at weekly frequency. The dependent variable is *SLF volumes* scaled by bond outstanding amount. *RB hold* denotes the one period lagged Riksbank's government bond holdings scaled by bond outstanding amount, *RB purch* is the Riksbank's government bond purchases scaled by bond outstanding amount, *SLF premium* is the premium of the Security Lending Facility (SLF) decided by the Swedish DMO, *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$, *Issuance* is the lagged one period bond issuance volume on the primary market scaled by outstanding amount, *Repo mrkt rep* is the one period lagged net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market scaled by bond outstanding amount, *Repo mrkt all* is the one period lagged net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database scaled by bond outstanding amount. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

An increase in the SLF premium - *SLF Premium* - is negatively associated with the usage of the SLF, suggesting that beyond scarcity the cheaper the SLF is to access, the more it is used. Here it is important to remember that the SLF premium is determined as a fixed spread to the monetary policy rate and thus fundamentally exogenous to the daily vagaries of the repo market. In addition, the coefficient of the interaction term $Premium_{i,t} * Purchases_{i,t}$ is positive, indicating that it weakens the total (marginal) effect of *RB Purch* on the SLF. In other words, the lower the premium (more negative), the lower the total impact of *RB Purch* on the usage of the SLF whereas the effect of the *Premium* is amplified by *RB Purch*.[13]

The variables *Repo Mrkt All* and *Repo Mrkt Rep* in equation 1 measure the net demand for government bonds in the repo market based on different counterparties. *Repo mrkt all* is calculated as the net collateralized lending of cash with government bonds as collateral of the reporting counterparties to all participants in the repo market, including primary dealers. Thus, it captures the overall demand of government bonds on the repo market at each time t. *Repo Mrkt Rep* measures the net government bond demand of the inter-primary dealer repo market. In the specification in equation 1, both variables are included with a one-period lag to account for potential delayed effects of repo market dynamics on the SLF and to reduce concerns about reverse causality by ensuring that explanatory variables precede the outcome in time.[14] As reported in columns 4 and 5 in Table 3, we find that after the start of the QE only the inter-dealer net demand has a statistically significant effect on the SLF. We come back to this result later in this section.

To further corroborate our results, we estimate equation 1 but with the variable *Spread* measured as the difference between the repo market yield and the SLF yield for each bond i at time t. As discussed above, such a difference represents the opportunity cost of accessing the facility and it is influenced by changes in the policy rate as well as changes to the repo market yield that do not depend on the policy rate. We report the results in Table 4, column (2). The sample period is 2010-2020 and therefore much shorter than in our baseline results of Table 3 where the sample period is 2002-2023 (June) and reported

[13]The marginal effect of *Purchases* on $SLF_{i,t}$ is $\beta_2 + \beta_4 \cdot Premium_{i,t}$. Since $SLF\ Premium_{i,t} < 0$ for all observations and $\beta_4 > 0$, the interaction term reduces the effect of Purchases because $\beta_4 \cdot Premium_{i,t}$ is negative. Similarly, the positive sign of β_4 determines the amplifying effect of $RBPurch$ on the marginal effect of $SLFPremium$, with the marginal effect of *Premium* being equal to $\beta_3 + \beta_4 \cdot Purchases_{i,t}$.

[14]Reverse causality could arise if SLF volumes influence repo market activity. While this possibility cannot be entirely ruled out, it is likely limited given that repo market activity is primarily driven by factors such as bank fundamentals, regulatory constraints, and broader monetary and macroeconomic conditions. To assess this, we regressed SLF volumes on repo market activity as in the following equation:

$$\begin{aligned} Repo\ Mrkt^{j}_{i,t} = \alpha_i + \gamma_t + \beta_1 Holdings_{i,t-1} + \beta_2 Purchases_{i,t} + \\ \beta_3 Premium_{i,t} + \beta_4 Premium_{i,t} * Purchases_{i,t} + \beta_5 X_{i,t} + SLF_{i,t} + \epsilon_{i,t}. \end{aligned} \tag{2}$$

with $j = Rep$ or $j = All$. We found no significant effect. The results are reported among the robustness checks in Appendix I.

for comparison in column (1). The variables in column (2) are statistically significant and exhibit the expected sign - except for the measure of repo market activity, which is not significant. These estimates, however, are based on a much shorter sample.[15] In particular, the *Spread* variable is statistically significant and it has a negative sign. This indicates that the closer the repo market yield is to the SLF repo yield, the higher the volume of bonds sourced from the SLF. In other words, the narrower the difference between repo market and SLF yield, the more attractive it becomes to place liquidity at the Swedish DMO - offering no counterparty risk and the ability to source all required government bonds on-demand.

Table 4: Panel regression results: alternative SLF premium measure

	Dependent variable:	
	SLF volumes	
	(1)	(2)
RB hold	0.08***	0.13**
	(0.01)	(0.05)
RB purch	1.70***	1.01*
	(0.63)	(0.60)
SLF Premium	0.16***	
	(0.04)	
Interaction	3.47**	
	(1.63)	
Spread		−0.21***
		(0.06)
Interaction spread		−4.67*
		(2.82)
Issuance	−0.06	−0.63**
	(0.25)	(0.25)
Repo Mrkt Rep	0.01**	0.03
	(0.01)	(0.03)
Twoways fixed effects	*Yes*	*Yes*
Clustered error	*Yes*	*Yes*
Observations	3,073	262
R^2	0.07	0.15

Note: The table shows twoways fixed effect panel regression results of the baseline model as in equation 1 with data aggregated at weekly frequency. The dependent variable is *SLF volumes* scaled by bond outstanding amount. *RB hold* denotes the one period lagged Riksbank's government bond holdings scaled by bond outstanding amount, *RB purch* is the Riksbank's government bond purchases scaled by bond outstanding amount, *SLF premium* is the premium of the Security Lending Facility (SLF) decided by the Swedish DMO, *Interaction* denotes the interaction term $Premium_{i,t} * RB\ purch_{i,t}$, *Issuance* is the lagged one period bond issuance volume on the primary market scaled by outstanding amount, *Spread* is the difference between the repo market yield and the SLF yield, *Interaction_spread* denotes the interaction term $Spread_{i,t} * RB\ purch_{i,t}$, *Repo mrkt rep* is the one period lagged net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market scaled by bond outstanding amount, *Repo mrkt all* is the one period lagged net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database scaled by bond outstanding amount. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

[15] To compute the variable *Spread*, for each bond i at each time t, we have calculated the difference between the weekly moving averages of the SLF yield and matched them with the available repo market yield data, which were also provided as weekly moving averages.

5.3.2 Announcement effects

In this section, we investigate the impact of *Purchases* at announcement days. The literature on unconventional monetary policy has focused mainly on the consequences of QE measures on long-term government and corporate bond yields (see, for example, Krishnamurthy and Vissing-Jorgensen (2011) and Swanson (2021)). However, this focus on long-maturity instruments has left important short-term dynamics insufficiently explored. Much less is known about the impact of QE announcements on shorter market rates and even less about how it influences the usage of the SLF. This gap in the literature extends to the behavior of intermediaries that rely on backstops such as the SLF. Would primary dealers increase their demand in the SLF already before the bond scarcity that would follow after the purchases?

We found the Riksbank QE to be an important factor in driving the SLF usage, and, while a priori unclear, it seems reasonable that purchases announcements would already have a material impact on SLF volumes. This would be the case, for example, if announcements served as a catalyst to obtain the bonds that the central bank committed to buy. We would expect measures of market turnover, turnover ratio and measures of market price impact to be affected as well as primary dealers intermediate the higher bond demand in the market.

Figure 7 describes the Riksbank auction cycle. The Riksbank made QE auction announcements on Friday afternoon before auction day, after market closing on that day. The auction day, barred few holidays and other special days, occurred on Thursdays the following week. Settlements, following financial market conventions, occurred two working days after auction (t+2) and therefore during the week after the auction.

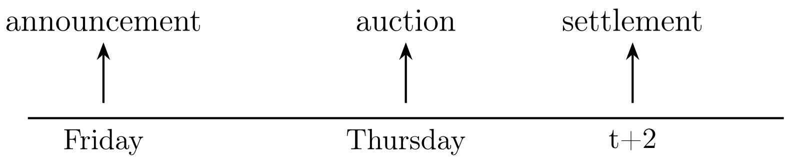

Figure 7: Riksbank's auction cycle

In order to understand the impact of purchases announcements, we estimate the following panel regression with time and by bond fixed effects at daily frequency:

$$Y_{i,t} = \alpha_i + \gamma_t + \beta RB\ Purch_{i,t} + \epsilon_{i,t} \tag{3}$$

where, as in equation 1, $Y_{i,t}$ denotes the volumes traded in the SLF of bond i at announcement time t and $RB\ Purch$ is, as before, the Riksbank QE purchases. Both variables are measured as share of outstanding volumes. Table 5 shows the results. Announcements were typically made on Fridays after market close at 4.15 p.m.. We therefore estimate equation 3 with announcements fixed at the closest Mondays, Tuesdays and Wednesdays before actual purchases which typically were made on Thursdays.[16]

Table 5: Announcement effect regression results

	Dependent variable:			
	SLF volume			
	(1)	(2)	(3)	(4)
RB purch	0.723***			
RB purch_monday		0.504**		
RB purch_tuesday			0.461**	
RB purch_wednesday				0.536**
Fixed effect (twoways)	*Yes*	*Yes*	*Yes*	
Observations	12,436	12,436	12,436	12,436
R^2	0.003	0.001	0.001	0.001

Note: The table shows twoways fixed effect panel regression results of the model as in equation 3 with data at daily frequency. The dependent variable is *SLF volume* scaled by bond outstanding amount. *RB purch* is the Riksbank's government bond purchases scaled by bond outstanding amount at settlement day. The variables *RB purch_monday*, *RB purch_tuesday*, *RB purch_wednesday* capture the announcement effects of Riksbank's purchases on the Mondays, Tuesdays and Wednesdays following Friday announcement after market close. The symbols ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered along the time dimension.

As columns (2)-(4) show, the announcements turn out to be significant and with the expected sign. In addition, the impact was relatively large, with a coefficient being about 70 percent of the coefficient in column (1) where we report the results of actual purchases for comparison. The evidence in Table 5 suggests that when Riksbank announced its purchases of QE bonds, primary dealers accessed the SLF and sourced the bonds before actual purchases. They could have done so either for their own books or as an intermediary; for example, if a customer asked for the same bond that the Riksbank announced it would buy and the primary dealer accessed the SLF to satisfy the demand of that customer. Blix Grimaldi et al.(2024) show that QE announcements had no meaningful impact on measures of market liquidity, including turnover-based and price-based measures.[17] The results of the announcements in Blix Grimaldi et al.(2024) do not support the idea that market liquidity may have improved with the QE announcements, as market participants may have become more willing to trade the bonds that were covered by the QE announcements of the central bank. Rather, they show that it was the actual outright purchase that increased the liquidity of Swedish government bonds.

Usage of the SLF before Riksbank purchases may have been initiated by the opportunity to sell the bonds to Riksbank, which acquired the bonds at an auction procedure where it is likely that some bidders can sell a price higher than the market average. Laséen (2023) find

[16]We correct the announcement days for holidays. For example, if the market was closed on Monday because of a holiday, the effect of announcements is measured on Tuesday.

[17]Blix Grimaldi et al.(2024) liquidity measures are transaction-based measures and exclude transactions with the Riksbank and the DMO.

that the local supply curve for individual participants is upward-sloping in the price. Bonds acquired through the SLF need to be returned to the DMO as the typical repo trade is one day with start the next day - a T/N repo. Laséen (2023) finds that the dynamic response of market yields to marginal repo yield is positive but short-lived. Riksbank purchases pushed up the market price of the purchased bonds with the price coming down to a level comparable to the pre-auction after about 5 days. Primary dealers could make a profit only if they were able to return the bond to the SLF at a price lower than the one they sold to the Riksbank net of the repo costs. We find that the average rolling days per bond for the T/N facility is about 5 days after the QE start. This strongly suggests that primary dealers returned the bonds to the DMO and closed the repo trade only after the positive price impact of the Riksbank's purchases had dissipated.

The results presented in this section on QE announcement effects are novel and add to the results of the broader literature on monetary policy announcements.

5.3.3 The swap facility price change

The results of the preceding section point to a disconnect between the ultimate goal of the SLF (improving market liquidity) and the way in which in practice the bonds sourced through the SLF have been used. In this section, we investigate two different events. First, in December 2019, with the intent of improving market liquidity, the Swedish DMO decreased the premium charged to primary dealers on the repo swap facility from 30 to 20 basis points while leaving unchanged the premium on the two cash facilities (ON and TN facilities). The decision was reversed in August 2021. Second, the premium on the swap facility was reduced again to 20 basis points in June 2022. We therefore investigate how those changes in the swap facility premium affected the cash facilities. Equation 4 summarizes our model:

$$\begin{aligned} Facility^j_{i,t} = \alpha_i + \gamma_t + \beta_1 Holdings_{i,t-1} + \beta_2 Purchases_{i,t} + \beta_3 Premium_{i,t} + \\ \beta_4 Premium_{i,t} * Purchases_{i,t} + \beta_5 X_{i,t} + \beta_6 D\_1 + \beta_7 D\_2 + \epsilon_{i,t}. \end{aligned} \tag{4}$$

where $Facility^j_{i,t}$ denotes the volumes in the facility j, being either the T/N or the O/N facility or the repo swap facility. D_1 is a dummy variable for the period December 2019 to August 2021 and D_2 for the period June 2022 to June 2023 when changes were made in the repo swap facility.[18] We report the results in Table 6.

[18]Changes in both volumes and premium were made in December 2019 and kept until August 2021. In December 2019, the yield on the swap facility was lowered by lowering the premium by 10 basis points to 20 basis points and the volume limit was lifted to 4 billion SEK from 2 billion SEK per government bond and primary dealer. The yield on the two cash facilities - O/N and T/N - was left unchanged. The decision on the repo swap facility yield was reversed in August 2021 whereas the limit was kept in place

Table 6: Regression results with price change of the repo swap facility

	Dependent variable:		
	TN	ON	RS
	(1)	(2)	(3)
D_1	−0.02***	−0.001	0.01***
	(0.002)	(0.001)	(0.001)
D_2	0.03***	−0.002**	0.003*
	(0.003)	(0.001)	(0.002)
Premium	0.08**	0.01	−0.06**
	(0.03)	(0.01)	(0.02)
RB hold	0.04***	0.002*	0.002
	(0.01)	(0.001)	(0.004)
RB purch	1.83***	0.22	0.34
	(0.57)	(0.16)	(0.77)
Interaction	4.44***	0.50	0.64
	(1.47)	(0.43)	(2.25)
Issuance	−0.12	−0.02	−0.19
	(0.22)	(0.06)	(0.11)
Repo Mrkt All	0.01***	0.0003*	−0.0001
	(0.001)	(0.0002)	(0.001)
Clustered error	*Yes*	*Yes*	*Yes*
Observations	3,073	1,917	1,089
R^2	0.21	0.02	0.03

Note: The table shows panel regression results with individual fixed effects of the model as in equation 4 for different specifications of the dependent variable. In column (1)-(3) the dependent variable is volume traded in the T/N, O/N and repo swap facility scaled by bond outstanding amount, respectively. *D_1* and *D_2* are dummy variables that take value 1 during December 2019-August 2021 and June 2022-June 2023, and zero otherwise, respectively; *RB hold* denotes the one period lagged Riksbank's government bond holdings scaled by bond outstanding amount; *RB purch* is the Riksbank's government bond purchases scaled by bond outstanding amount; *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$; *Issuance* is the lagged one period bond issuance volume on the primary market scaled by outstanding amount; *Repo mrkt all* is the one period lagged net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database scaled by bond outstanding amount. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

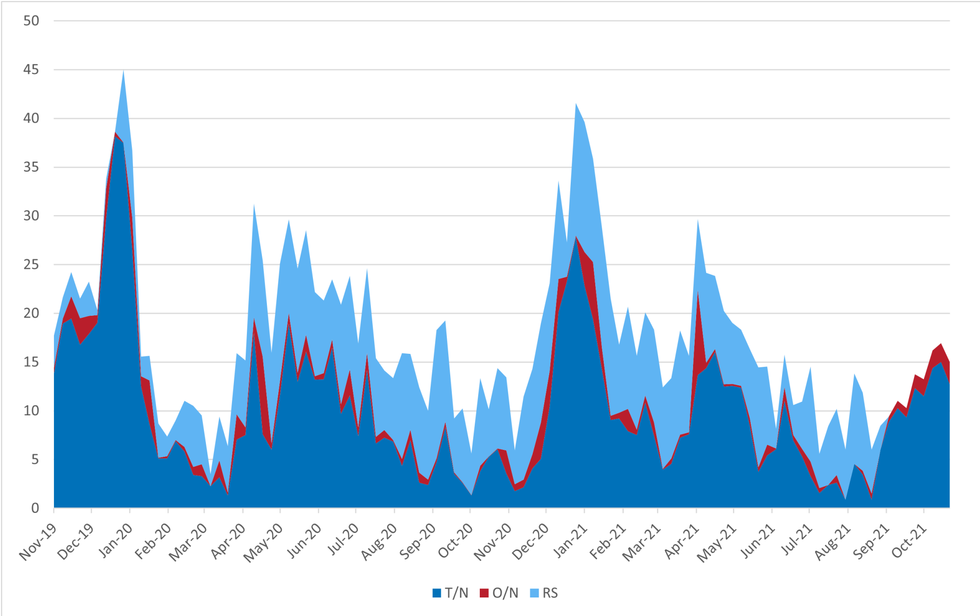

Figure 8: Repo swap facility yield change and usage of the SLF, by type

We find that while the changes made in the repo swap facility yield between December 2019 and August 2021 can have helped market liquidity by providing after-sought bonds at a lower premium, during that period the usage of the T/N facility decreased whereas, as expected, the volumes traded in the swap facility increased. Comparing weekly volumes in a short time window around the price change in December 2019, it appears that the decrease in T/N usage was almost completely compensated by the increase in the repo swap facility.[19] In addition, the increased usage of the repo swap facility occurs during the period of the lower premium on the facility and goes back to very low levels after. At the same time, as shown in Figure 8, during this period the volumes traded in the T/N facility decline, pointing to a substitution effect between the repo swap and T/N facility.

As shown in Figure 9 perceived liquidity as measured through survey responses collected by the Swedish DMO decreased significantly during this period, mainly driven by primary dealers. The change in the swap facility premium may have mitigated these perceptions and helped primary dealers keep trading government bonds. During the period in which the swap facility was accessible at a lower premium, the Riksbank increased purchases (Figure 10). It is reasonable that these new and larger purchases of Riksbank may have given an incentive to primary dealers to source bonds from the less onerous swap facility while decreasing their demand of bonds in the T/N facility.

until September 2022. Although both changes to price and volume limits may have affected the trading in the facilities, we find that a dummy for the period in which only conditions on volumes were kept is insignificant. This suggests that the effect of the premium dominates the volume change. We report the results among robustness checks in Appendix I.

[19]To minimize the influence of year-end effects, we compare the SLF volumes in the week before the price change and after year-end.

Changes in the repo swap facility made in June 2022 occurred at a time in which perceived liquidity had deteriorated significantly for all market actors. The Riksbank purchased relatively low volumes of government bonds during the same period. As expected, the volumes of the repo swap facility increased as they did in the T/N facility.

Overall, the results presented in this section further highlight the complex interaction between the central bank QE, the SLF, and repo market participants.

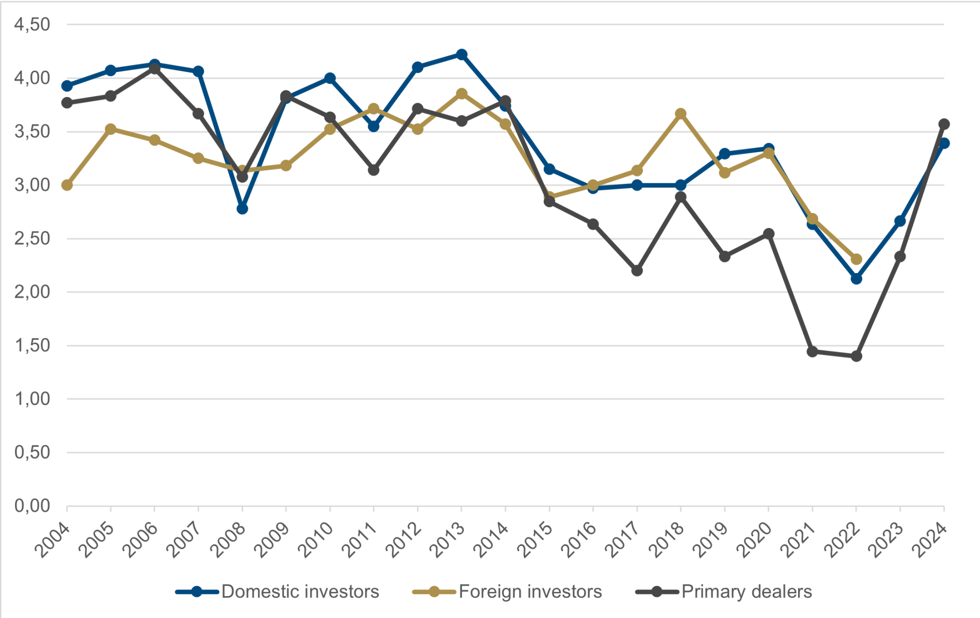

Figure 9: Perceived government securities market liquidity, Swedish DMO survey

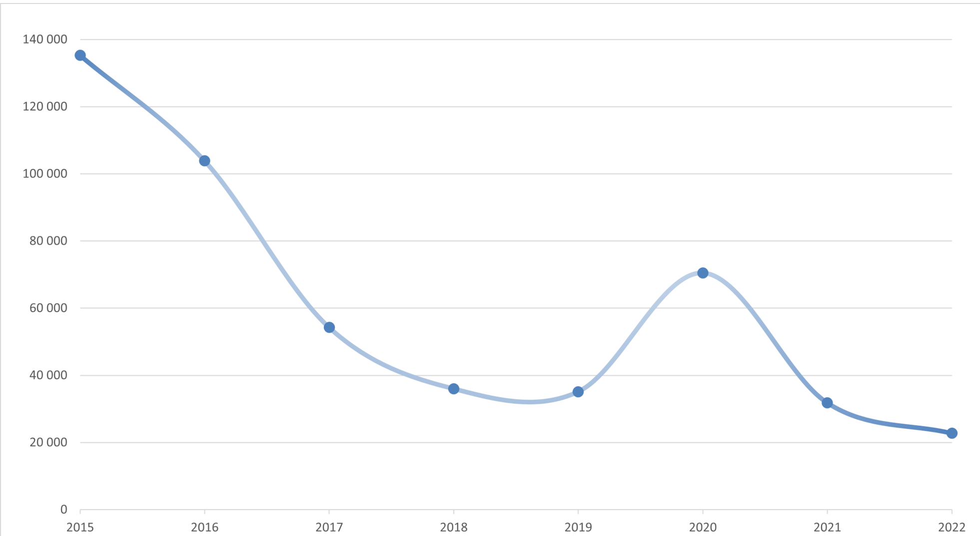

Figure 10: Riksbank's government bond purchases (in million SEK).

6 Theory

In the next section, we present a model that explains our empirical findings.

6.1 Model set-up

We use a deterministic, infinite time model with discount rate β. Each period is divided into two subperiods. There is a mass one of infinitely lived primary dealers (PD). Additionally, there is one institution, the central bank.
There are two markets: a so-called repo market which takes place in the 1^{st} subperiod and a so-called spot market which takes place in the 2^{nd} subperiod. The figure below gives an overview.

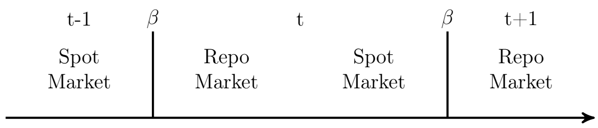

Figure 11: Timeline

There is a stock $\bar{A}$ of assets and $\bar{M}$ of money. Assets can be interpreted as a Lucas tree where the fruits are normalized at zero. They can have convenience value on top of the fruits (see below). Next to assets and money there is a so-called spot market-good (spot-good). It can be produced (consumed) by all agents, i.e. primary dealers and investors, at linear disutility (linear utility) during the second subperiod. The marginal disutility of production (-1) equals the marginal utility of consumption (+1).[20]

In the spot market there is frictionless all-to-all trade among primary dealers (Walrasian market). Primary dealers can acquire and sell assets against spot-good at nominal price q. Primary dealers can build up or decrease their money holdings against spot-good at price ϕ. A_D and M_D denote the asset and money holdings of the primary dealers after the spot market. Where necessary we will also distinguish the holdings by their future type i which is introduced below.[21]

At the beginning of the period primary dealers receive an exogenous demand shock with probability $1 > \mu \geq 0.5$. The demand shock can be interpreted as investors (not modelled) contacting a primary dealer to borrow assets through repurchase agreements on their behalf.[22] The primary dealers with the positive demand shock receive utility $\kappa > 0$ per asset

[20]This implies that it is not worth to produce the good for consumption by itself. Also, linearity implies that wealth effects do not matter.

[21]The asset and money holdings are in that case denoted by A_{iD} and M_{iD}.

[22]This is consistent with the fact that investors generally trade through their primary dealers and do not access the market themselves.

they borrow on the repo market at the end of this market. κ can be interpreted as a reimbursement of an investor for a convenience yield he acquires by holding the asset. The primary dealers who receive a demand shock are denoted of type $i = 1$. The other primary dealers are of type $i = 0$.

In the repo market, there is bilateral matching among primary dealers. Each primary dealer of type $i = 0$ is matched with one of type $i = 1$. Matched primary dealers maximize their common surplus by borrowing and lending their money to each other. The trade has to be collateralized with assets they currently possess and is reversed the next subperiod. The value of the assets as collateral is according to their current spot market price q. The repo rate r_r on borrowed money is determined by bargaining which splits the common surplus according to their bargaining powers. Primary dealers of type $i = 0$ have bargaining power $\theta > 0$. The other have bargaining power $(1 - \theta) > 0$. The payment is due in the next subperiod and there is full commitment. A_0 and A_1 denote the asset holdings of the matched primary dealers of type i after the repo market (without acquirements through any facility described below) before the trade is reversed the next subperiod. A_{in} denote the holdings of the unmatched ones. The same notation is used for money.

After assets and money change hands the primary dealers can access the facilities before the repo market ends. Primary dealers have access to a central bank reverse repo facility (which can also be called securities lending facility) and a deposit facility.[23] The former pays the next subperiod interest rate r_f and the latter interest rate $r_d \geq r_f$ on deposited money. Compared to the deposit facility the reverse repo facility is collateralized with assets valued at the current spot market price q. The acquired assets of the primary dealers of type i through the reverse repo facility are denoted by A_i^f. A_{in}^f denote the holdings of the unmatched ones.

6.2 Maximization problems and equilibrium

6.2.1 Maximization problems first subperiod

At the beginning of a new period primary dealers hold an inventory of assets A_{iD} and have money holdings M_{iD}.

We start by describing the maximization problem of the unmatched primary dealer i in the

[23] For simplicity, in our theoretical setup the central bank manages the SLF. This simplification does not affect the results.

first subperiod:

$$\max_{A^f_{in}, M_{in}} (i\kappa + \phi q)A_{iD} + [i\kappa + \phi(1 + r_f)q]A^f_{in} + \phi(1 + r_d)M_{in}$$
$$\text{s.t.}$$
$$\begin{aligned} qA^f_{in} + M_{in} &= M_{iD}, \\ A^f_{in} &\geq 0, \\ M_{in} &\geq 0. \end{aligned} \tag{5}$$

The unmatched primary dealer receives the convenience yield κ on his inventory of assets A_{iD} and the assets have a value equal to their real price ϕq per asset in the next subperiod. As he is unmatched he cannot trade the assets. But the primary dealer can decide into which one (or both) of the two facilities he wants to deposit his money M_{iD} to maximize his surplus. The first option is to deposit it into the deposit facility and receive the real gross interest rate $\phi(1+r_d)$ on the money M_{in} he deposits. The second option is to deposit money into the reverse repo facility and borrow assets A^f_{in} for one subperiod. During the time he holds the assets, he receives the convenience yield κ per asset. Also, the facility pays the real gross interest rate $\phi(1 + r_f)$ on the deposit value qA^f_{in}. All choice variables must be non-negative.

The maximization problem of the matched primary dealer of type i in the first subperiod is given by:

$$\max_{A_1, A_0, A^f_1, A^f_0, M_1, M_0} \quad (S_1 + S_0)$$
$$\text{s.t.}$$
$$\begin{aligned} S_1 &= (1 - \theta)(S_1 + S_0), \\ A_1 + A_0 &= A_{1D} + A_{0D}, \\ qA^f_1 + qA^f_0 + M_1 + M_0 &= M_{1D} + M_{0D}, \\ qA_1 + qA^f_1 + M_1 &= M_{1D} + qA_{1D}, \\ \min\{A_1, A_0, A^f_1, A^f_0, M_1, M_0\} &\geq 0. \end{aligned} \tag{6}$$

The surplus is defined by

$$\begin{aligned} S_i \equiv &[i\kappa + \phi q](A_{iD} - A_{in}) + [i\kappa + \phi(1 + r_r)q](A_i - A_{iD}) + [i\kappa + \phi(1 + r_f)q](A^f_i - A^f_{in}) \\ &+ \phi(1 + r_d)(M_i - M_{in}). \end{aligned}$$

The surplus is the lifetime utility the primary dealer has with the trade minus the lifetime utility without the trade with the counterparty. On their inventory of assets A_{iD} they enjoy the convenience yield and they are valued (and potentially sold in the next spot market) at real price ϕq. The same holds for the assets when they use the outside option and do not trade as when unmatched. They would hold the amount of assets A_{in} in their inventory. On all the assets borrowed on the repo market $(A_i - A_{iD})$ (or lent out if negative), they enjoy (forgoe) the convenience yield κ. Additionally, they receive (or pay) the gross real interest rate $\phi(1 + r_r)$ on the money lent out (borrowed) which is equivalent to the value of assets borrowed (lent out). The analogous argument holds for all the assets acquired via the central bank's reverse repo facility, $(A_i^f - A_{in}^f)$. This facility pays interest rate r_f. Lastly, the deposit facility pays a real gross interest rate $\phi(1 + r_d)$ per unit of money deposited. They can deposit the money they bring from the last spot market M_{iD}. The same also holds for their outside option where they don't trade as if they are unmatched and deposit M_{in}. In addition, they receive (forgoe) the interest rate r_d on all the money borrowed (lent out) through the repo market, $(M_i - M_{iD})$.

The primary dealers maximize their joint surplus $S_1 + S_0$. They set the interest rate in the repo market r_r as such that the primary dealer of type $i = 1$ holds after the trade the share equal to his bargaining power $(1 - \theta)$ of the overall surplus (see first constraint). When trading the primary dealers have a joint inventory of assets equal to $A_{1D} + A_{0D}$ which they can allocate among each other by choosing A_0 and A_1 (see second constraint). Their joint money balances $M_{0D} + M_{1D}$ they can keep on holding as money or put it into the reverse repo facility and receive assets which are valued at price q in exchange for it (third constraint). Importantly, each trade of assets among primary dealers must be in exchange for money. Assets are valued according to their current value in the spot market q. This is implied by the fourth constraint. The fourth constraint can be interpreted as a collateral constraint or as a non-leverage constraint. The latter speaks to the fact that you cannot have more wealth in terms of assets and money after the trade than before.[24] Lastly, after the repo market all money and asset holdings (incl. the ones acquired through the facility) must be non-negative.

The fourth constraint in combination with linear utility in the spot market implies that the trades among primary dealers can be interpreted as repos. It implies that there are only trades where money is handed out in direct exchange for an equal value of assets. Linearity implies that we can assume that the money and the assets are exchanged back in the next subperiod.[25]

[24] Note that we could also write the maximization problem with respect to the following two constraints instead of the fourth: $qA_1 + qA_1^f + M_1 \leq M_{1D} + qA_{1D}$ and $qA_0 + qA_0^f + M_0 \leq M_{0D} + qA_{0D}$. This is equivalent to our maximization problem 6 as the latter constraint combined with $A_1 + A_0 = A_{1D} + A_{0D}$ and $qA_1^f + qA_0^f + M_1 + M_0 = M_{1D} + M_{0D}$ implies that the first mentioned constraint must hold with equality.

[25] The reason is that due to linearity primary dealers will adjust their inventories of assets and cash in the next subperiod independent of their current wealth. If assets are acquired (or reduced) through the reverse leg of a repo transaction or via a purchase (or sale) in the spot market is equivalent. In both cases, the assets are valued at the prevailing price q, and any excess (or shortfall) position can be adjusted at

6.2.2 Equilibrium selection

We take the following equilibrium assumption:

Assumption 1. *In equilibrium* $r_d \geq r_f$ *and* $\frac{\kappa}{q} \geq \phi(r_d - r_f)$.

We only want to look at an equilibrium where the deposit rate lies above the facility rate, $r_d > r_f$. Uncollateralized deposits at the central bank are renumerated at a higher interest rate than collaterlized ones, which is a natural assumption.

Also, we assume that $\frac{\kappa}{q} \geq \phi(r_d - r_f)$. This means that it is worth to forgoe the interest difference between the two facilities to attain the convenience yield κ per monetary unit exchanged into assets. Without this assumption one can show that primary dealers would never tap the reverse repo facility which is not what we observe empirically.

6.2.3 Equilibrium allocation first subperiod

Solving the maximization problem leads to the following first subperiod allocations:

Lemma 1. *The following characterises the equilibrium allocations in the first subperiod.*

a) Primary dealers of type i decisions if matched and $M_{1D} \geq qA_{0D}$ *are:*

$$\begin{array}{ll} A_1 = A_{0D} + A_{1D}, & A_0 = 0, \\ A_1^f = \frac{M_{1D}}{q} - A_{0D}, & A_0^f = 0, \\ M_1 = 0, & M_0 = M_{0D} + qA_{0D}. \end{array}$$

b) Primary dealers of type i decisions if matched and $M_{1D} < qA_{0D}$ *are:*

$$\begin{array}{ll} A_1 = \frac{M_{1D}}{q} + A_{1D}, & A_0 = A_{0D} - \frac{M_{1D}}{q}, \\ A_1^f = 0, & A_0^f = 0, \\ M_1 = 0, & M_0 = M_{1D} + M_{0D}. \end{array}$$

c) Primary dealers of type i decisions if unmatched/their outside options are:

$$\begin{array}{ll} A_{1n} = A_{1D}, & A_{0n} = A_{0D}, \\ A_{1n}^f = \frac{M_{1D}}{q}, & A_{0n}^f = 0, \\ M_{1n} = 0, & M_{0n} = M_{0D}. \end{array}$$

Proof. See Appendix 9.1. □

this same price in the spot market. The same holds for money.

If matched, the PD1 would like to acquire as many assets as he can, while the PD0 would like to acquire as much money as he can. If $M_{1D} \geq qA_{0D}$ (case a), then the price of assets is enough low such that the PD1 does not have to exhaust his full money balances to repo in all the assets of the PD0. He deposits the remaining balances into the reverse repo facility to acquire even more assets. If $M_{1D} \geq qA_{0D}$ (case b), then the price of assets is enough high such that the PD0 does not have to repo out all his assets to acquire all the money balances of the PD1. He keeps the remaining assets in his inventory. Note that if $M_{1D} = qA_{0D}$, then all the assets of the matched primary dealers end up in the hands of the PD1 and all the money of the matched primary dealers in the hands of the PD0. No matched primary dealer uses the reverse repo facility.

If unmachted or if they would use their outside options (case c) both types of primary dealers can't adjust their asset inventory. With respect to money it is beneficial for the PD1 to deposit it into the reverse repo facility to acquire more assets. The PD0 deposits its money into the deposit facility as he has no special use for the collateral of the reverse repo facility while he receives a higher interest rate at the deposit facility.

6.2.4 Maximization problem second subperiod

We denote the value function of the primary dealers at the beginning of the period by $V(A_{iD}, M_{iD})$. It is given by

$$\begin{aligned} V(A_{iD},M_{iD}) &= (2\mu - 1)N_1 \\ &+ (1-\mu)\left[M_{10} + M_{01}\right] + \max_{A_{iD,+},M_{iD,+}} -\phi q A_{iD,+} - \phi M_{iD,+} + \beta V(A_{iD,+}, M_{iD,+}) \end{aligned} \tag{7}$$

with

$$N_1 \equiv [\kappa + \phi q]A_{1n} + [\kappa + \phi(1+r_f)q]A^f_{1n} + \phi(1+r_d)M_{1n},$$

$$\begin{aligned} &M_{10} + M_{01} \\ &\quad \equiv [\kappa + \phi q]A_1 + \phi q A_0 + [\kappa + \phi(1+r_f)q]A^f_1 + \phi(1+r_f)qA^f_0 + \phi(1+i_d)(M_1 + M_0), \end{aligned}$$

and for the unmatched primary dealer
$A_{1n} = A_{1D}$, $A_{0n} = A_{0D}$, $A^f_{1n} = \frac{M_{1D}}{q}$, $A^f_{0n} = 0$, $M_{1n} = 0$, $M_{0n} = M_{0D}$,

and for the matched primary dealer if $M_{1D} \geq qA_{0D}$
$A_1 = A_{0D} + A_{1D}$, $A_0 = 0$, $A^f_1 = \frac{M_{1D}}{q} - A_{0D}$, $A^f_0 = 0$, $M_1 = 0$, $M_0 = M_{0D} + qA_{0D}$,

and otherwise
$A_1 = \frac{M_{1D}}{q} + A_{1D}$, $A_0 = A_{0D} - \frac{M_{1D}}{q}$, $A_1^f = 0$, $A_0^f = 0$, $M_1 = 0$, $M_0 = M_{1D} + M_{0D}$.

The value function includes the maximization problem of all primary dealers in the second subperiod. In the spot market primary dealers can buy and sell assets at real price ϕq to optimally adjust their inventory before they take part in the next repo market. They can also adjust their money balances, which have a real value of ϕ. With probability $(1-\mu)$ a primary dealer is matched the next subperiod and either is a PD1 or a PD0. If he is a PDi, he acquires the profit (not surplus) $M_{i,-i} \equiv [i\kappa + \phi q]A_i + [i\kappa + \phi(1+r_f)q]A_i^f + \phi(1+r_d)M_i$ when matching with a PD0. As there is a mass μ of PD1 but only $(1-\mu)$ are matched with a PD0, the mass $(\mu - (1-\mu)) = (2\mu - 1)$ of PD1 stays unmatched. They acquire the profit N_1 according to the above definition.

6.2.5 Equilibrium allocation second subperiod

In this subsection we describe the solution to the second subperiod problem. We assume a constant real value of money and real value of assets in steady state.[26]

Lemma 2. *The following characterizes the equilibrium prices and quantities (steady state) in the second subperiod.*

a) Prices in the second subperiod if $M_{1D} \geq qA_{0D}$ are:

$$q = \left[1 + \frac{1-2\mu}{1-\mu}\right] \frac{M_D}{A_D},$$

$$\phi q = \frac{\beta\mu\kappa}{1 - \beta(1-\mu)(2+r_d) - \beta(2\mu-1)}.$$

b) Prices in the second subperiod if $M_{1D} < qA_{0D}$ are:

$$q = \frac{\beta(1-\mu)i_d}{\beta(1-\mu)i_d + \beta(2\mu-1)r_f} \frac{M_D}{A_D},$$

$$\phi q = \frac{\beta\mu\kappa}{1 - \beta(1-\mu)(2+i_d) - \beta(2\mu-1)(1+r_f)}.$$

[26] One can show that a steady state with constant positive or negative growth in the real value of money is not possible as a solution.

c) Quantities in the second subperiod are:

$$M_D = \bar{M},$$
$$A_D = \bar{A}.$$

Proof. See Appendix 9.2. □

6.2.6 Equilibrium definition

Lastly, we define the equilibrium.

Definition 1 (**Equilibrium**). *An equilibrium consists of*

a) the interest rates r_r, r_d, r_f,

b) the real value of assets q and of money ϕ,

c) the money balances M_i, M_{in}, M_D,

d) the asset holdings A_i, A_{in}, A_i^f, A_{in}^f, A_D,

for $i \in \{0, 1\}$. The primary dealers solve the maximization problems (5) if unmatched and (6) if matched in the bilateral repo market. They solve the maximization problem (7) in the spot market which has to clear. The interest rates r_d and r_f are set by the central bank.

6.3 Results - Facility usage without QE

In this subsection we describe our results based on the equilibrium without QE. Afterwards we introduce QE and explain how the equilibrium dynamics change.

For expositional purposes we illustrate the facility dynamics in Figure 12. There are overall four primary dealers in the repo market. Three are PD1 who have a higher utility from assets than the only PD0. The PD1 are therefore the natural demander of assets while the PD0 is the natural supplier of them. The repo market is an OTC market with search and matching frictions. Each PD0 matches with a PD1. Given we are in a situation with so-called excess demand where there are more PD1 than PD0, two of the PD1 stay unmatched. We use μ as a measure of excess demand.

The matched primary dealer couple exchanges assets versus money and bargain over the repo rate r_r. The PD1 acquires as much assets as he can from the PD0 and the PD0 demands as much money as he can from the PD1. After the exchange, the PD0 puts all his money into the uncollateralized central bank deposit facility at rate r_d. He prefers the deposit facility over the reverse repo facility as it pays a higher interest rate and he has not enough high utility of the latter's collateral to make up for the interest rate difference.

If the PD1 has some money left after the repo market (which is sometimes but not always the case[27]), he taps the reverse repo facility to acquire even more assets with the remaining money which he deposits at rate r_f. His utility of the collateral provided is enough high to make him willing to forgo the interest rate difference $r_d - r_f$.
Due to excess demand, the unmatched primary dealers could not find and satisfy their asset demand in the repo market. The unmatched PD1 therefore tap the reverse repo facility and acquire the assets there. The same reasoning applies for them as for the matched PD1 why they prefer the reverse repo facility over the deposit facility.

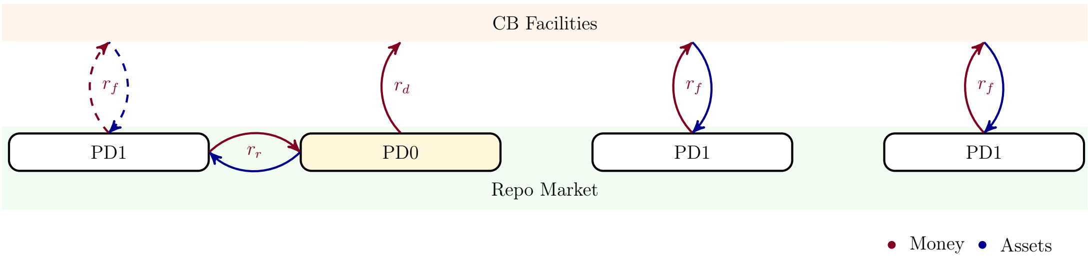

Figure 12: Repo market and facility usage

In a next step we analyze the total amount of money deposited into the reverse repo facility. We define the total amount of money in the reverse repo facility as

$$V^f \equiv (1-\mu)q(A_0^f + A_1^f) + (2\mu - 1)qA_{1n}^f.$$

Our results lead us to the following proposition:

Proposition 1 (Reverse repo facility volumes)**.** *The total amount of money in the reverse repo facility is positive ($V^f > 0$) despite the fact that it pays a lower rate than the repo market and the deposit facility, i.e. $r_r > r_f$ and $r_d > r_f$. The total amount is the higher, the higher excess demand is, i.e.* $\frac{dV^f}{d\mu} > 0$.

Proof. See Appendix 9.3. □

Search frictions are key for the results described in Proposition 1. If the repo market would be centralized and not OTC, the repo market rate would adjust until either the demand equals the supply or the rate falls so low that it equals the facility rate. We would never observe any facility usage as long as there is a positive spread between the market rate and the reverse repo facility rate. But we observe this spread (which can be as high as 50bp) while the facility is used in high volumes.

[27]The PD1 has some remaining money after the repo trade left if his initial money was higher than what he needed to acquire all the assets of the PD0 at rate q.

Next, we discuss the repo market rate in equilibrium.

Proposition 2. *The interest rate in the repo market is*

$$r_r = \theta r_f + (1 - \theta) r_d.$$

Proof. See Appendix 9.4. □

The repo market rate r_r lies in-between the deposit rate r_d and the reverse repo facility rate r_f. If the PD0 has full bargaining power, $\theta = 1$, then $r_r = r_f$. The PD0 who pays the repo market rate r_r to the PD1 has to pay only as much interest as if the PD1 would receive if he would use his outside option instead of doing the repo trade, i.e. attain the assets through the the reverse repo facility.

If the PD1 has full bargaining power, $(1-\theta) = 1$, then $r_r = r_d$. He extracts the full interest gain the PD0 has from depositing the money he receives in the repo trade into the deposit facility. In this case we also observe that the repo market rate disconnects from the deposit rate. This is in line with our empirical discussion in section 4.4 where we argued that repo market rates anchored to the SLF yield rather than the interest rate corridor of the Riksbank's operational framework. We empirically observe a disconnect from the money market benchmark rates.

6.4 Equilibrium with QE

In a next step we describe a version of our model where in addition the central bank also conducts QE. We assume QE takes place before the end of the repo market after repo trades were conducted and facilities were used. Every PD has the option to sell its assets to the central bank at a given nominal price.[28] If they do so, they forgoe the utility κ if they are of type $i = 1$.[29] Otherwise the model stays the same.

We set the price the central bank pays when buying assets to match several empirical observations. First, the central bank paid a slightly higher price than the market, i.e. we assume that the price equals $q + \epsilon$ with $\epsilon > 0$. We want to assume that ϵ is small in particular that $\kappa > \phi\epsilon$ such that not all primary dealers want to sell all their assets to the central bank and any other demand would not be met anymore. Second, we choose to set the pricing as such that some primary dealers (who previously preferred to hold uncollateralized deposits at the central bank) start to use the facility just for attaining the assets they can sell to the central bank, i.e. $\phi\epsilon > \phi(r_d - r_f)q$. This is in line with our

[28] QE takes place at the end of the repo market such that agents have no unlimited riskless arbitrage opportunity if the price paid by the central bank is greater than the spot market price q.

[29] As pointed out in Section 6.1, κ can be interpreted as a reimbursement from an investor. If a primary dealer of type $i = 1$ sells an asset to the central bank, he forgoes this reimbursement.

result on annoucement effects described in Section 5.3.2. We therefore take the following assumption:

Assumption 2. *We assume that* $\kappa > \phi\epsilon > \phi(r_d - r_f)q$.

Given this assumption, we derive the equilibrium values for the equilibrium with QE.

Lemma 3. *With QE, there exists a continuum of equilibria where*

$$\begin{aligned} &A_1 \in [U, L], && A_0 = A_{1D} + A_{0D} - A_1, \\ &A_1^f = \tfrac{M_{1D}}{q} + A_{1D} - A_1, && A_0^f = \tfrac{M_{0D}}{q} - A_{1D} + A_1, \\ &M_1 = 0, && M_0 = 0, \end{aligned}$$

with $U \equiv \min\left\{A_{1D} + A_{0D}, \frac{M_{1D}}{q} + A_{1D}\right\}$ *and* $L \equiv \max\left\{A_{1D} - \frac{M_{0D}}{q}, 0\right\}$ *and for both* $i = 0, 1$ $M_{in} = 0$, $A_{in} = A_{iD}$ *and* $A_{in}^f = \frac{M_{iD}}{q}$.

Proof. See Appendix 9.5.[30] □

One implication of this indeterminacy result for the broader policy discussion is that primary dealers may substantially reduce their reliance on the repo market during QE, potentially raising liquidity concerns.

We do not solve for the equilibrium prices and quantities in the second subperiod. We do not need them to state our results and indeterminacy and a potentially increasing monetary stock and decreasing asset stock due to QE add complexity. Regarding the latter, we would like to point out that the stock of money and assets can vary under QE, but for our results, specifying their exact levels is not needed.

6.5 Results - Facility usage with QE

If the central bank conducts QE, then even the PD0 use the reverse repo facility, meaning that in general $A_0^f > 0$.[31] Instead of depositing their money into the deposit facility, they put their money into the reverse repo facility and borrow assets to sell them to the central bank. We depict this situation in Figure 13. The central bank pays a slightly higher price than the spot market where they re-buy the assets afterwards to return them to the facility.[32]

Our discussion leads us to the following proposition below. We assume that the stock of money is equal or larger under QE compared to without.[33]

[30] The reason that there is a continuum of equilibria is that the repo market does not generate any additional (but also not less) surplus for the matched primary dealer couples. Therefore the amounts traded in the repo market are indeterminate (see the proof of Proposition 4 for the surplus values).

[31] Only if $A_1 = A_{1D} - \frac{M_{0D}}{q}$, then $A_0^f = 0$.

[32] The spot market is not shown in the figure.

[33] The assumption is realistic given that QE decreases the stock of assets in the market and increases the one of money over time.

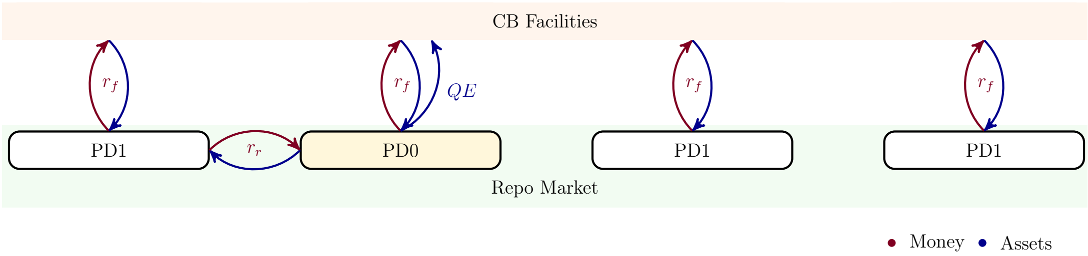

Figure 13: Repo market and facility usage with QE

Proposition 3. *With QE the total amount of money in the reverse repo facility is higher compared to without.*

Proof. See Appendix 9.6 □

It can be that the matched PD1 is depositing a different (and potentially lower) amount of money into the reverse repo facility in the case with QE than without. Nevertheless, the result holds independent of this fact.[34]

In a next step we discuss the interest rate in the repo market in the equilibrium with QE and compare it to the one in the equilibrium without.

Proposition 4. *The interest rate in the repo market during QE is lower compared to without and equals the floor rate r_f, i.e.*

$$r_r = r_f.$$

Proof. See Appendix 9.7. □

QE presses the repo market rate down to the floor, i.e. the reverse repo facility rate. This can be seen as a result of the cash borrower's enhanced bargaining position. The repo market rate fully decouples from the deposit rate, which can also be interpreted as the policy rate. The reason is that the PD0 deposits the money acquired through the repo market in the reverse repo facility at rate r_f instead of putting it into the deposit facility at the higher rate r_d as before.[35]

[34] The reason is that the sum of money placed in the facility by the matched primary dealer couple is with QE always the same.

[35] These rates are the only additional benefit the PD0 has from participating in the repo market compared to using his outside option. The outside option is to keep the asset inventory and sell it to the central bank (with QE) or the spot market (without QE) without going through the repo market and the facilities first. As only benefits in addition to the outside option are redistributed and the additional benefits (but not the overall) are lower for the PD0 with QE, this lowers the repo rate he has to pay to the PD1.

7 Conclusions and policy discussion

This paper makes a novel contribution by dissecting the intricate interplay between quantitative easing (QE) and the securities lending facility (SLF) at a level of detail that has not been previously explored. We leverage a confidential, uniquely granular dataset that combines information on volumes and yields from Riksbank's QE purchases, the Swedish DMO's SLF transactions, and over-the-counter repo market deals from a major Swedish dealer. Notably, separation of the SLF's management, managed by the public debt management office rather than the central bank, provides a natural experimental setting that reinforces causal interpretations. Our analysis reveals that the interaction between these two policy instruments is far more complex than previously understood and has important implications for both market functioning and monetary policy transmission.

Our empirical results indicate that increases in the QE portfolio are strongly associated with a marked increase in the use of the SLF. During months when QE purchases expand, the usage of the SLF increases by an amount roughly equal to half the size of those QE purchases, with a persistent stock effect that elevates average usage by 5-10 percent. Beyond the direct impact of QE, we show that a narrowing spread between the SLF yield and the repo market rate is associated with a higher usage of the SLF, effectively turning the SLF yield into the floor for secured lending rates and decoupling repo market rates from traditional monetary policy benchmarks. We also provide novel evidence on the rolling behavior of primary dealers and the effect of the QE purchases announcements on SLF usage. These findings show that QE not only influences market liquidity in government bond markets directly through asset purchases but also indirectly by affecting funding conditions and collateral availability in the repo market.

To interpret these empirical results, we develop a theoretical model that explains the factors shaping SLF usage under both normal conditions and periods of reduced bond free float, such as during the QE program. This model clarifies the conditions under which primary dealers switch from conventional funding sources to the SLF, particularly in the presence of asset scarcity and search frictions. This theoretical contribution not only explains the mechanism behind the increased reliance on the SLF but also highlights how such reliance can potentially alter the transmission of monetary policy by decoupling market rates from traditional policy benchmarks.

Our findings suggest that while QE may have been useful as a monetary policy tool, its interaction with SLF usage may inadvertently strengthen primary dealers' bargaining power and lead to a first-resort use of the facility, challenging its intended role as a backstop mechanism. This raises some critical questions about the interaction of QE with the SLF and implications for market liquidity and the effectiveness of monetary policy transmission. The policy implications of our results are critically dependent on the prevailing QE transmission channel.

Some members of the Riksbank Executive Board (e.g. Floden (2022)) argued that a main effect of the QE program was to lower the repo market rate substantially below the policy rate. As many market participants consider the repo rate to be the most relevant short-term risk-free rate, this view suggests that the significant reduction in bond free float - and the consequent deterioration in market liquidity in the government bond market - was an essential mechanism and unavoidable consequence for achieving a more expansionary monetary policy stance. A possible counterargument to this view is that cutting the policy rate further could have induced a similar effect on short-term market rates without causing a discrepancy between the two rates. But concerns about possible negative effects on the banking system may have induced policymakers to refrain from further interest rate cuts. With this view of the transmission mechanism of QE, and the benefits of hindsight, the Riksbank could have argued (1) increasing the SLF yield spread from 40 bps to allow for a more stimulative policy stance, or (2) that further government bond purchases once the lower bound on the market repo rate was reached would be ineffective.

In contrast, an alternative view is that the QE transmission channel operates through market risk absorption by the central bank, thereby reducing long-term risk premia and bond yields, which in turn lowers broader financing costs, including bank funding costs, corporate bond yields, and ultimately interest rates on consumer and firm loans. With this view, the deterioration in market liquidity is an unintended side consequence of the QE policy, which could be mitigated through reinserting the purchased bonds back to the private sector through repo transactions. Thus, again with this view, the increase in SLF usage during QE may be seen as a positive development, as it partially alleviated the unintended market liquidity squeeze. An alternative would have been that the Riksbank could have participated (directly or indirectly via working with the SNDO) to repo a share of the QE purchases sufficiently large to stabilize the market repo rate in the vicinity of the policy rate. Had this stategy been employed, the use of the SNDO facility had likely not explanded beyond historical low levels, since the 40 bps spread would have remained prohibitive.

In this paper, we do not take a stance on which of these views is correct (and the truth might of course be a combination of the two), but our findings underscore the importance of aligning the design of QE programs with the operational parameters of the SLF facility. Such an alignment is essential to ensure policy effectiveness and mitigate unintended consequences that may arise from the over-reliance on backstop mechanisms.

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8 Appendix I: Robustness checks

Table 7: Regression results: baseline model with daily data

	Dependent variable:					
	SLF Volumes					
	(1)	(2)	(3)	(4)	(5)	(6)
RB Hold	0.01	0.05***	0.05***	0.05***	0.06***	0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
RB purch	0.75***	0.65***	1.28**	1.28**	1.51**	1.26**
	(0.22)	(0.20)	(0.63)	(0.63)	(0.64)	(0.62)
SLF premium		0.25***	0.24***	0.24***	0.22***	0.24***
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Interaction			2.08	2.08	2.59	2.02
			(1.67)	(1.67)	(1.69)	(1.66)
Issuance				−0.02	−0.01	−0.02
				(0.11)	(0.11)	(0.11)
Repo mrkt rep					0.04***	
					(0.01)	
Repo mrkt all						0.003
						(0.002)
Twoways fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Clustered error	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,430	11,936	11,936	11,936	11,833	11,936
R^2	0.003	0.06	0.06	0.06	0.06	0.06

Note: The table shows twoways fixed effect panel regression results of the baseline model as in equation 1. *RB hold* denotes the one period lagged Riksbank's government bond holdings, *RB purch* is the Riksbank's government bond purchases, *SLF premium* is the premium of the Security Lending Facility (SLF) decided by the Swedish DMO, *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$, *Issuance* is bond issuance on the primary market, *Repo mrkt rep* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market, *Repo mrkt all* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

Table 8: Regression results: baseline model with monthly data

	Dependent variable:					
	SLF Volumes					
	(1)	(2)	(3)	(4)	(5)	(6)
RB Hold	0.04*	0.06***	0.06***	0.06***	0.06***	0.07***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
RB purch	0.34***	0.28***	0.82***	0.85***	0.83***	0.95***
	(0.09)	(0.08)	(0.26)	(0.26)	(0.27)	(0.28)
SLF premium		0.22**	0.17*	0.17**	0.18**	0.10
		(0.09)	(0.09)	(0.09)	(0.08)	(0.09)
Interaction			1.66**	1.66**	1.62**	1.86**
			(0.76)	(0.74)	(0.75)	(0.77)
Issuance				−0.77*	−0.74*	−0.94**
				(0.40)	(0.44)	(0.42)
Repo mrkt rep					−0.0002	
					(0.0004)	
Repo mrkt all						0.005*
						(0.003)
Time effect	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	
Clustered error	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	
Observations	862	834	834	834	834	834
R^2	0.02	0.06	0.07	0.07	0.07	0.08

Note: The table shows twoways fixed effect panel regression results of the baseline model as in equation 1. *RB hold* denotes the one period lagged Riksbank's government bond holdings, *RB purch* is the Riksbank's government bond purchases, *SLF premium* is the premium of the Security Lending Facility (SLF) decided by the Swedish DMO, *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$, *Issuance* is bond issuance on the primary market, *Repo mrkt rep* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market, *Repo mrkt all* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

Table 9: Regression results, baseline model with MOVE index and individual fixed effects

	Dependent variable	
	SLF Volumes	
	(1)	(2)
RB hold	0.04***	0.04***
	(0.01)	(0.01)
RB purch	1.72***	1.81***
	(0.62)	(0.60)
SLF premium	0.09***	0.06*
	(0.03)	(0.03)
Interaction	4.49***	4.44***
	(1.61)	(1.56)
Issuance	−0.10	−0.22
	(0.23)	(0.22)
Repo Mrkt Rep	0.01***	
	(0.003)	
Repo Mrkt All		0.01***
		(0.001)
MOVE	0.0004***	0.0003***
	(0.0001)	(0.0000)
Individual fixed effects	*Yes*	*Yes*
Clustered error	*Yes*	*Yes*
Observations	3,073	3,073
R^2	0.08	0.15

Note: The table shows individual fixed effect panel regression results of the baseline model as in equation 1. *RB hold* denotes the one period lagged Riksbank's government bond holdings, *RB purch* is the Riksbank's government bond purchases, *SLF premium* is the premium of the Security Lending Facility (SLF) decided by the Swedish DMO, *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$, *Issuance* is bond issuance on the primary market, *Repo mrkt rep* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market, *Repo mrkt all* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database. *Move* denotes the MOVE Index (Merrill Option Volatility Estimate) measure of bond market volatility. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

Table 10: Regression results with dependent variable in logs

	Dependent variable:					
	SLF volumes, in logs					
	(1)	(2)	(3)	(4)	(5)	(6)
RB hold	3.58***	4.58***	4.58***	4.58***	4.53***	4.57***
	(0.36)	(0.35)	(0.35)	(0.35)	(0.36)	(0.35)
RB purch	22.53***	19.32***	18.64*	18.54*	18.44*	18.32*
	(3.86)	(3.55)	(10.68)	(10.67)	(10.79)	(10.74)
SLF premium		6.91***	6.92***	6.93***	7.16***	7.06***
		(0.76)	(0.80)	(0.80)	(0.84)	(0.81)
Interaction			−2.02	−2.04	−2.22	−2.68
			(31.58)	(31.58)	(31.87)	(31.71)
Issuance				−2.12	−2.15	−1.90
				(5.23)	(5.18)	(5.24)
Repo Mrkt Rep					−0.07	
					(0.15)	
Repo Mrkt All						−0.01
						(0.02)
Twoways fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Clustered error	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	3,187	3,073	3,073	3,073	3,073	3,073
R^2	0.05	0.09	0.09	0.09	0.09	0.09

Note: The table shows individual fixed effect panel regression results of the baseline model as in equation 1. *RB hold* denotes the one period lagged Riksbank's government bond holdings, *RB purch* is the Riksbank's government bond purchases, *SLF premium* is the premium of the Security Lending Facility (SLF) decided by the Swedish DMO, *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$, *Issuance* is bond issuance on the primary market, *Repo mrkt rep* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market, *Repo mrkt all* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database. *Move* denotes the MOVE Index (Merrill Option Volatility Estimate) measure of bond market volatility. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

Table 11: Regression results with regressors at different lags

	Dependent variable:					
	SLF volumes					
	(1)	(2)	(3)	(4)	(5)	(6)
RB hold, 1)	0.07***	0.08***	0.07***	0.06***	0.08***	0.06***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
RB purch	0.55***	0.57***	0.54***	0.55***	0.58***	0.55***
	(0.16)	(0.15)	(0.15)	(0.14)	(0.15)	(0.11)
SLF premium	0.23	0.17	0.23	0.23	0.16	0.23***
						(0.02)
Issuance (lag 2)	−0.04	−0.01	−0.04			
Repo Mrkt Rep (lag 2)		0.02				
Repo Mrkt All (lag 2)			−0.0000			
Issuance (lag 3)				−0.20	−0.18	−0.21
						(0.16)
Repo Mrkt Rep (lag 3)					0.02	
Repo Mrkt All (lag 3)						0.0003
						(0.001)
Twoways fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Clustered error	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	3,073	3,073	3,073	3,073	3,073	3,073
R^2	0.06	0.07	0.06	0.06	0.07	0.06

Note: The table shows twoways fixed effect panel regression results of the baseline model as in equation 1. *RB hold* denotes the one period lagged Riksbank's government bond holdings, *RB purch* is the Riksbank's government bond purchases, *SLF premium* is the premium of the Security Lending Facility (SLF) decided by the Swedish DMO, *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$, *Issuance* is bond issuance on the primary market, *Repo mrkt rep* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market, *Repo mrkt all* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database. *Move* denotes the MOVE Index (Merrill Option Volatility Estimate) measure of bond market volatility. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

Table 12: Regression resultswith volume-weighted *SLF premium*

	Dependent variable:				
	SLF volumes				
	(1)	(2)	(3)	(4)	(5)
RB hold	0.03**	0.05***	0.05***	0.07***	0.05***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
RB purch	0.62***	0.57***	0.57***	0.57***	0.57***
	(0.16)	(0.15)	(0.15)	(0.14)	(0.15)
SLF premium weighted		0.16***	0.16***	0.11***	0.16***
		(0.03)	(0.03)	(0.03)	(0.03)
Issuance			−0.05	−0.05	−0.06
			(0.24)	(0.26)	(0.24)
Repo mrkt Rep				0.02***	
				(0.01)	
Repo mrkt All					0.001
					(0.001)
Twoways fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Clustered error	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	3,187	3,073	3,073	3,073	3,073
R^2	0.01	0.04	0.04	0.05	0.04

Note: The table shows twoways fixed effect panel regression results of the baseline model as in equation 1 with the *SLF premium* computed as the volume-weighted sum of premium on the three underlying facility, i.e. the premiums on two cash facility (T/N and O/N) and on the repo swap facility. *RB hold* denotes the one period lagged Riksbank's government bond holdings, *RB purch* is the Riksbank's government bond purchases; *Issuance* is bond issuance on the primary market; *Repo mrkt rep* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market; *Repo mrkt all* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

Table 13: Regression results with regressors at different lags and weighted *SLF premium*

	Dependent variable:		
	SLF volumes		
	(1)	(2)	(3)
RB hold	0.05***	0.07***	0.05***
	(0.01)	(0.01)	(0.01)
RB purch	0.57***	0.61***	0.56***
	(0.16)	(0.15)	(0.15)
SLF premium weighted	0.16	0.09***	0.16***
		(0.03)	(0.03)
Issuance (lag 1)	−0.04	−0.11	
Issuance (lag 2)	0.001	0.02	
Issuance (lag 3)	−0.19	−0.16	
Repo Mrkt Rep (lag 1)		−0.002	
Repo Mrkt Rep (lag 2)		0.001	
Repo Mrkt Rep (lag 3)		0.03	
Issuance (lag 1)			−0.07
			(0.24)
Repo Mrkt All (lag 1)			−0.0002
Repo Mrkt All (lag 2)			−0.0002
Repo Mrkt All (lag 3)			0.001
Twoways fixed effects	*Yes*	*Yes*	*Yes*
Clustered error	*Yes*	*Yes*	*Yes*
Observations	3,073	3,073	3,073
R^2	0.04	0.06	0.04

Note: The table shows twoways fixed effect panel regression results of the baseline model as in equation 1 with the *SLF premium* computed as the volume-weighted sum of premium on the three underlying facility, i.e. the premiums on two cash facility (T/N and O/N) and on the repo swap facility and regressors at different lags. *RB hold* denotes the one period lagged Riksbank's government bond holdings, *RB purch* is the Riksbank's government bond purchases; *Issuance* is bond issuance on the primary market, at lag 1:3; *Repo mrkt rep* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market at lag 1:3; *Repo mrkt all* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database, at lag 1:3. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

Table 14: Reverse causality regression results

	Dependent variable:	
	Repo Mrkt Rep	*Repo Mrkt All*
	(1)	(2)
RB hold	−0.61***	−0.73*
	(0.08)	(0.38)
RB purch	−4.08	−7.09
	(7.33)	(23.98)
SLF premium	3.12***	9.78***
	(0.41)	(0.99)
Interaction	−5.86	−26.23
	(19.19)	(62.93)
Issuance	−0.89	0.77
	(1.04)	(4.70)
SLF volumes	0.25	0.26
	(0.18)	(0.51)
Twoways fixed effects	*Yes*	*Yes*
Clustered error	*Yes*	*Yes*
Observations	2,770	2,770
R^2	0.33	0.15

Note: The table shows twoways fixed effect panel regression results of the model as in equation 2 . The dependent variable in column (1) *Repo mrkt rep* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) versus other primary dealers (reporting counterparties of the Riksbank) in the repo market and in column (2) *Repo mrkt all* is the net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database. *RB hold* denotes the one period lagged Riksbank's government bond holdings, *RB purch* is the Riksbank's government bond purchases; *SLF premium* is the premium of the Security Lending Facility (SLF) decided by the Swedish DMO, *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$, *Issuance* is bond issuance on the primary market; *SLF volumes* is overall volume traded in the SLF. The ***, **, and * marks denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

Table 15: Regression results with SLF price changes

	Dependent variable:		
	TN	ON	Repo swap
	(1)	(2)	(3)
D_1	−0.02***	−0.0004	0.01***
	(0.002)	(0.001)	(0.001)
D_1a	−0.004	−0.0001	−0.004
	(0.002)	(0.001)	(0.002)
D_2	0.03***	−0.001	0.004*
	(0.003)	(0.001)	(0.002)
SLF premium	0.08**	0.01	−0.06**
	(0.03)	(0.01)	(0.02)
RB hold	0.04***	0.002	0.002
	(0.01)	(0.001)	(0.004)
RB purch	1.83***	0.20	0.34
	(0.57)	(0.15)	(0.77)
Interaction	4.42***	0.45	0.63
	(1.47)	(0.41)	(2.26)
Issuance	−0.12	−0.01	−0.19
	(0.22)	(0.06)	(0.11)
Repo Mrkt Rep	0.01***		−0.0001
	(0.001)		(0.001)
Repo Mrkt All		0.002**	
		(0.001)	
Individual fixed effects	*Yes*	*Yes*	*Yes*
Clustered error	*Yes*	*Yes*	*Yes*
Observations	3,073	1,917	1,089
R^2	0.21	0.02	0.04

Note: The table shows panel regression results with individual fixed effects of the model as in equation 4 for different specifications of the dependent variable. In column (1)-(3) the dependent variable is volume traded in the T/N, O/N and repo swap facility scaled by bond outstanding amount, respectively. *D_1* and *D_1a* are dummy variables that take value 1 during December 2019-August 2021 and September 2021-September 2022 and zero otherwise, respectively. *D_2* takes value 1 in the period June 2022-June 2023 and zero otherwise; *RB hold* denotes the one period lagged Riksbank's government bond holdings scaled by bond outstanding amount; *RB purch* is the Riksbank's government bond purchases scaled by bond outstanding amount; *Interaction* denotes the interaction term $Premium_{i,t} * RBpurch_{i,t}$; *Issuance* is the lagged one period bond issuance volume on the primary market scaled by outstanding amount; *Repo mrkt all* is the one period lagged net government bond demand of primary dealers (reporting counterparties of the Riksbank) towards all repo market participants as reported in the Riksbank's SELMA database scaled by bond outstanding amount. The symbols ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are clustered at time dimension.

9 Appendix II: Proofs

9.1 Proof of Lemma 1

Proof. We first solve the maximization problem of the unmatched primary dealer i in the first subperiod given by (5). The Lagrangian is

$$\mathcal{L} = (i\kappa+\phi q)A_{iD}+\left[i\kappa + \phi(1 + r_f)q\right] A^f_{in}+\phi(1+r_d)M_{in}+\lambda_C(M_{iD}-qA^f_{in}-M_{in})+\lambda_f A^f_{in}+\lambda_m M_{in}.$$

The first order conditions with respect to A^f_{in} and M_{in} are

$$[i\kappa + \phi(1 + r_f)q] - \lambda_C q + \lambda_f = 0,$$
$$\phi(1 + r_d) - \lambda_C + \lambda_m = 0.$$

We define $R^f_i \equiv \frac{i\kappa}{q} + \phi(1 + r_f)$ and $R^m \equiv \phi(1 + r_d)$. Rearranging yields

$$R^f_i + \frac{\lambda_f}{q} = \lambda_C,$$
$$R^m + \lambda_m = \lambda_C.$$

Therefore if $R^m > R^f_i$ then $M_{in} = M_{iD}$ and $A^f_{in} = 0$ and otherwise $M_{in} = 0$ and $A^f_{in} = \frac{M_{iD}}{q}$. We assumed that $r_d \geq r_f$ and $\frac{\kappa}{q} \geq \phi(r_d - r_f)$ (see the discussion in Section 6.2.2). This implies that $R^f_1 > R^m > R^f_0$. Therefore $M_{0n} = M_{0D}$, $A^f_{0n} = 0$, $M_{1n} = 0$ and $A^f_{1n} = \frac{M_{1D}}{q}$. In addition the unmatched primary dealers keep holding their inventory of assets: $A_{1n} = A_{1D}$ and $A_{0n} = A_{0D}$. Given they are unmatched they cannot adjust it.

In a next step we solve the maximization problem of the matched primary dealer in the first subperiod given by (6). We use $A_{1n} = A_{1D}$ and $A_{0n} = A_{0D}$ from above to simplify. The Lagrangian is

$$\begin{aligned}\mathcal{L} &= \kappa(A_1 - A_{1D} + A^f_1 - A^f_{1n}) + \phi(1 + r_f)q(A^f_1 - A^f_{1n} + A^f_0 - A^f_{0n})\\ &+ \phi(1 + r_d)(M_1 - M_{1n} + M_0 - M_{0n})\\ &+ \lambda_M \left[M_{1D} + M_{0D} - M_1 - M_0 - qA^f_1 - qA^f_0\right]\\ &+ \lambda_{1C} \left[M_{1D} + qA_{1D} - qA_1 - qA^f_1 - M_1\right]\\ &+ \lambda_1 A_1 + \lambda_0(A_{0D} + A_{1D} - A_1) + \lambda_{1f} A^f_1 + \lambda_{0f} A^f_0 + \lambda_{1m} M_1 + \lambda_{0m} M_0.\end{aligned}$$

Note that the constraint $S_1 = (1 - \theta)(S_1 + S_0)$ (see the maximization problem (6)) is not part of the Lagrangian. The reason is that the interest rate r_r will be set as such that this constraint will be satisfied. Since r_r does not affect the other parts of the program, we can disregard this constraint, solve the problem and then solve for r_r.

The first order conditions with respect to the choice variables are

$$\begin{aligned}
\kappa - \lambda_{1C} q + \lambda_1 - \lambda_0 &= 0, \\
\kappa + \phi(1 + r_f) q - \lambda_M q - \lambda_{1C} q + \lambda_{1f} &= 0, \\
\phi(1 + r_d) - \lambda_M - \lambda_{1C} + \lambda_{1m} &= 0, \\
\phi(1 + r_f) q - \lambda_M q + \lambda_{0f} &= 0, \\
\phi(1 + r_d) - \lambda_M + \lambda_{0m} &= 0.
\end{aligned}$$

We define $R_1 \equiv \frac{\kappa}{q}$. Rearranging yields

$$\begin{aligned}
R_1 + \frac{\lambda_1 - \lambda_0}{q} &= \lambda_{1C}, \\
R_1^f + \frac{\lambda_{1f}}{q} &= \lambda_{1C} + \lambda_M, \\
R^m + \lambda_{1m} &= \lambda_{1C} + \lambda_M, \\
R_0^f + \frac{\lambda_{0f}}{q} &= \lambda_M, \\
R^m + \lambda_{0m} &= \lambda_M.
\end{aligned}$$

We can combine the second and third equation as well as the fifth and sixth equation. This yields

$$\begin{aligned}
R_1^f - R^m &= \lambda_{1m} - \frac{\lambda_{1f}}{q}, \\
R_0^f - R^m &= \lambda_{0m} - \frac{\lambda_{0f}}{q}.
\end{aligned}$$

If $R_1^f > R^m$, then $\lambda_{1m} > 0, M_1 = 0$, otherwise $\lambda_{1f} > 0, A_1^f = 0$. If $R_0^f > R^m$, then $\lambda_{0m} > 0, M_0 = 0$, otherwise $\lambda_{0f} > 0, A_0^f = 0$.

Combining the third and the sixth equation yields

$$\lambda_{1m} - \lambda_{0m} = \lambda_{1C}.$$

We know that $\lambda_{1C} > 0$. This implies $\lambda_{1m} > 0$, $M_1 = 0$.

Combining the first, the second and the fourth equation yields

$$\lambda_{1f} - \lambda_{0f} = \lambda_1 - \lambda_0.$$

If $\lambda_{1f} - \lambda_{0f} > 0$, then $\lambda_1 > 0$ and therefore $A_1 = 0$. If $\lambda_{1f} - \lambda_{0f} < 0$, then $\lambda_0 > 0$ and therefore $A_0 = 0$.

As already pointed out above, we assumed that $r_d \geq r_f$ and $\frac{\kappa}{q} \geq \phi(r_d - r_f)$ which implies that $R_1^f > R^m > R_0^f$. We know that in this case $\lambda_{1m} > 0$, $M_1 = 0$ and $\lambda_{0f} > 0$, $A_0^f = 0$. To solve for the other variables, we have to distinguish two cases: $\lambda_0 > 0$ and $\lambda_0 = 0$.

Suppose $\lambda_0 > 0$. Then $A_0 = 0$. The first two constraints and $A_1 + A_0 = A_{1D} + A_{0D}$ imply

$$\begin{aligned} A_1 &= A_{0D} + A_{1D}, \\ A_1^f &= \frac{M_{1D}}{q} - A_{0D}, \\ M_0 &= M_{0D} + qA_{0D}. \end{aligned}$$

Suppose $\lambda_0 = 0$. From $\lambda_1 = \lambda_{1f} - \lambda_{0f}$ and $\lambda_{0f} > 0$ it follows that $\lambda_{1f} > 0$. Therefore $A_1^f = 0$. The first two constraints and $A_1 + A_0 = A_{1D} + A_{0D}$ imply

$$\begin{aligned} A_1 &= \frac{M_{1D}}{q} + A_{1D}, \\ M_0 &= M_{1D} + M_{0D}, \\ A_0 &= A_{0D} - \frac{M_{1D}}{q}. \end{aligned}$$

□

9.2 Proof of Lemma 2

Proof. We first derive N_1 and $M_{10}+M_{01}$ which we will insert into the maximization problem in equation (7). In a first step, we therefore insert the values in Lemma 1 into the definition of N_1. This yields

$$N_1 = [\kappa + \phi q]A_D + [\kappa + \phi(1 + r_f)q]\,\frac{M_D}{q}.$$

We first cover the case where $M_{1D} \geq qA_{0D}$. We know that in the repo market money and assets are exchanged. Assets as collateral are valued at the current spot market price q. We use the variable s to define the ratio at which money and assets are exchanged in the repo market: $(1 + \overline{s}) \equiv \frac{M_{1D}}{qA_{0D}}$. We need this ratio to derive the equilibrium values of money and assets described in Lemma 1 in terms of the primary dealer i's inventory A_{iD} and M_{iD}. Applying our definition for $\overline{s}$ in the equilibrium equations described in Lemma

1 yields the following asset and money holdings:

$$A_1 = \frac{1}{(1+\overline{s})}\frac{M_{1D}}{q} + A_{1D},$$
$$A_1^f = \frac{\overline{s}}{(1+\overline{s})}\frac{M_{1D}}{q},$$
$$M_0 = M_{0D} + qA_{0D}.$$

The other variables equal zero. Primary dealers do not know yet which type they are going to be in the next period and are therefore all equal when solving this maximization problem. This implies that $M_{1D} = M_{0D} = M_D$ and $A_{1D} = A_{0D} = A_D$. We insert the values into $M_{10} + M_{01}$.

$$M_{10} + M_{01} =$$
$$[\kappa + \phi q]\left[\frac{1}{(1+\overline{s})}\frac{M_D}{q} + A_D\right] + [\kappa + \phi(1+r_f)q]\left[\frac{\overline{s}}{(1+\overline{s})}\frac{M_D}{q}\right] + \phi(1+r_d)\left[M_D + qA_D\right].$$

We insert N_1 and $M_{10} + M_{01}$ into the maximization problem in (7). The primary dealers take the ratio $\overline{s}$ as given. The first order conditions are:

$$-\frac{\phi q}{\phi_+ q_+} + \beta(2\mu - 1)\left[\frac{\kappa}{\phi_+ q_+} + 1\right] + \beta(1-\mu)\left[\frac{\kappa}{\phi_+ q_+} + 2 + r_d\right] = 0,$$

$$-\frac{\phi}{\phi_+} + \beta(2\mu - 1)\left[\frac{\kappa}{\phi_+ q_+} + 1 + r_f\right] + \beta(1-\mu)\left[\frac{\kappa}{\phi_+ q_+} + 2 + r_d + \frac{\overline{s}}{(1+\overline{s})}r_f\right] = 0.$$

We assume that the real value of money ϕ and the real price of assets ϕq does not grow over time.[36] Solving for the steady state values yields:

$$\phi q = \frac{\beta\mu\kappa}{1 - \beta(1-\mu)(2+r_d) - \beta(2\mu-1)},$$

$$0 = \beta\left[(2\mu - 1) - \frac{\overline{s}(1-\mu)}{(1+\overline{s})}\right] r_f.$$

Rearranging the last equation yields $q = \left[1 + \frac{1-2\mu}{1-\mu}\right]\frac{M_D}{A_D}$.

Next, we cover the case where $M_{1D} < qA_{0D}$. Again, we define the ratio at which assets are exchanged versus money: $(1 - \underline{s}) \equiv \frac{M_{1D}}{qA_{0D}}$. As we again want s to be positive, we deduct it in the definition to accommodate for this second case. Applying our definition

[36] We also solved the general case with a constant growth steady state for the real value of money ϕ. The solution reveals though that the real value has to be constant over time.

for $\underline{s}$ in the equilibrium equations described in Lemma 1, yields:

$$A_1 = A_1 = \frac{M_{1D}}{q} + A_{1D},$$
$$A_0 = \underline{s}A_{0D},$$
$$M_0 = (1-\underline{s})qA_{0D} + M_{0D}.$$

The other variables equal zero. Due to the same reasoning as in the above case $M_{1D} = M_{0D} = M_D$ and $A_{1D} = A_{0D} = A_D$. Next, we insert the values into $M_{10} + M_{01}$.

$$M_{10} + M_{01} =$$
$$(\kappa + \phi q)\left[\frac{M_D}{q} + A_D\right] + \phi q \underline{s} A_D + \phi(1+r_d)\left[q(1-\underline{s})A_D + M_D\right].$$

Again, we insert N_1 and $M_{10} + M_{01}$ into the maximization problem in (7) and derive the first order conditions:

$$-\frac{\phi q}{\phi_+ q_+} + \beta(2\mu - 1)\left[\frac{\kappa}{\phi_+ q_+} + 1\right] + \beta(1-\mu)\left[\frac{\kappa}{\phi_+ q_+} + 2 + r_d(1-\underline{s})\right] = 0,$$

$$-\frac{\phi}{\phi_+} + \beta(2\mu - 1)\left[\frac{\kappa}{\phi_+ q_+} + 1 + r_f\right] + \beta(1-\mu)\left[\frac{\kappa}{\phi_+ q_+} + 2 + r_d\right] = 0.$$

Solving for the steady state values yields:

$$\phi q = \frac{\beta\mu\kappa}{1 - \beta(1-\mu)(2+r_d) - \beta(2\mu-1) + \beta(1-\mu)\underline{s}r_d},$$

$$0 = \beta\left[(2\mu - 1)r_f + (1-\mu)\underline{s}r_d\right].$$

Rearranging yields

$$q = \frac{\beta(1-\mu)i_d}{\beta(1-\mu)i_d + \beta(2\mu-1)r_f}\frac{M_D}{A_D},$$
$$\phi q = \frac{\beta\mu\kappa}{1 - \beta(1-\mu)(2+i_d) - \beta(2\mu-1)(1+r_f)}.$$

Lastly, the amount of assets and money demanded must equal the stock of available assets and money in that period. Therefore $M_D = \bar{M}$ and $A_D = \bar{A}$. □

9.3 Proof of Proposition 1

Proof. We insert the equilibrium values listed in Lemma 1 and Lemma 2 into the formula for V^f. This yields

$$V^f = (1-\mu)(\bar{M} - q\bar{A}) + (2\mu - 1)\bar{M} = \mu\bar{M} - (1-\mu)q\bar{A} > 0$$

with $q = \left[1 + (1-2\mu)(1-\mu)^{-1}\right]\frac{\bar{M}}{\bar{A}}$ if $\bar{M} \geq q\bar{A}$ and

$$V^f = (2\mu - 1)\bar{M} > 0$$

otherwise. The derivative with respect to μ is

$$\frac{dV^f}{d\mu} = \bar{M} + q\bar{A} - (1-\mu)\frac{\partial q}{\partial \mu}\bar{A} > 0$$

with $\frac{\partial q}{\partial \mu} = -\frac{1}{(1-\mu)^2}\frac{\bar{M}}{\bar{A}}$ if $\bar{M} \geq q\bar{A}$ and

$$\frac{dV^f}{d\mu} = 2\bar{M} > 0$$

otherwise. In addition we know that $r_d > r_f$ by Assumption 1 and Proposition 2 shows that in equilibrium $r_r > r_f$ given $\theta < 1$. □

9.4 Proof of Proposition 2

Proof. Inserting the equilibrium quantities into the definition for the surplus (see section 6.2.1) implies

$$S_1 = \phi(r_r - r_f)qA_{0D},$$
$$S_0 = \phi(r_d - r_r)qA_{0D}$$

if $M_{1D} \geq qA_{0D}$ and

$$S_1 = \phi(r_r - r_f)M_{1D},$$
$$S_0 = \phi(r_d - r_r)M_{1D}$$

if $M_{1D} < qA_{0D}$.

Inserting the surpluses into $S_1 = (1-\theta)(S_1 + S_0)$ (see section 6.2.1) and rearranging yields the repo market rate $r_r = \theta r_f + (1-\theta)r_d$. □

9.5 Proof of Lemma 3

Proof. We first solve the maximization problem of the unmatched primary dealer i in the first subperiod given by (5). The Lagrangian is

$$\mathcal{L} = \max\{(i\kappa + \phi q), \phi(\epsilon + q)\}A_{iD} + \max\{[i\kappa + \phi(1 + r_f)q], [\phi\epsilon + \phi(1 + r_f)q]\}A^f_{in} + \phi(1 + r_d)M_{in}$$
$$\lambda_C(M_{iD} - qA^f_{in} - M_{in}) + \lambda_f A^f_{in} + \lambda_m M_{in}.$$

We define $\hat{R}^f_i \equiv \max\{i\kappa, \phi\epsilon\}\frac{1}{q} + \phi(1 + r_f)$. Analogous to the proof of Lemma 1 the first order conditions with respect to A^f_{in} and M_{in} are

$$\hat{R}^f_i + \frac{\lambda_f}{q} = \lambda_C,$$
$$R^m + \lambda_m = \lambda_C.$$

From assumption 1 and 2 it follows that $\hat{R}^f_1 > \hat{R}^f_0 > R^m$. Therefore $M_{in} = 0$ and $A^f_{in} = \frac{M_{iD}}{q}$ for $i = 0, 1$. Also, the unmatched primary dealers keep holding their inventory of assets: $A_{1n} = A_{1D}$ and $A_{0n} = A_{0D}$.

In a next step we solve the maximization problem of the matched primary dealer in the first subperiod. Analogous to the proof of Lemma 1 the Lagrangian is

$$\begin{aligned}
\mathcal{L} = &\kappa(A_1 - A_{1D} + A^f_1 - A^f_{1n}) + \phi\epsilon(A_{1D} - A_1 + A^f_0 - A^f_{0n}) \\
&+ \phi(1 + r_f)q(A^f_1 - A^f_{1n} + A^f_0 - A^f_{0n}) + \phi(1 + r_d)(M_1 - M_{1n} + M_0 - M_{0n}) \\
&+ \lambda_M \left[M_{1D} + M_{0D} - M_1 - M_0 - qA^f_1 - qA^f_0\right] \\
&+ \lambda_{1C} \left[M_{1D} + qA_{1D} - qA_1 - qA^f_1 - M_1\right] \\
&+ \lambda_1 A_1 + \lambda_0(A_{0D} + A_{1D} - A_1) + \lambda_{1f}A^f_1 + \lambda_{0f}A^f_0 + \lambda_{1m}M_1 + \lambda_{0m}M_0.
\end{aligned}$$

The first order conditions with respect to the choice variables are

$$\begin{aligned}
\kappa - \phi\epsilon - \lambda_{1C}q + \lambda_1 - \lambda_0 &= 0, \\
\kappa + \phi(1 + r_f)q - \lambda_M q - \lambda_{1C}q + \lambda_{1f} &= 0, \\
\phi(1 + r_d) - \lambda_M - \lambda_{1C} + \lambda_{1m} &= 0, \\
\phi\epsilon + \phi(1 + r_f)q - \lambda_M q + \lambda_{0f} &= 0, \\
\phi(1 + r_d) - \lambda_M + \lambda_{0m} &= 0.
\end{aligned}$$

We define $\hat{R}_1 \equiv \frac{\kappa - \phi\epsilon}{q}$. Rearranging yields

$$\begin{aligned}
\hat{R}_1 + \frac{\lambda_1 - \lambda_0}{q} &= \lambda_{1C}, \\
\hat{R}_1^f + \frac{\lambda_{1f}}{q} &= \lambda_{1C} + \lambda_M, \\
R^m + \lambda_{1m} &= \lambda_{1C} + \lambda_M, \\
\hat{R}_0^f + \frac{\lambda_{0f}}{q} &= \lambda_M, \\
R^m + \lambda_{0m} &= \lambda_M.
\end{aligned}$$

The first order equations are analogous to the ones in proof of Lemma 1.

As already pointed out above, from assumption 1 and 2 it follows that $\hat{R}_1^f > \hat{R}_0^f > R^m$. We know that in this case $\lambda_{im} > 0$, $M_i = 0$ for $i = 0, 1$. From the constraints it follows that

$$\begin{aligned}
q(A_1^f + A_0^f) &= M_{1D} + M_{0D}, \\
A_1 + A_0 &= A_{1D} + A_{0D}, \\
q(A_1 + A_1^f) &= M_{1D} + qA_{1D}.
\end{aligned}$$

We rearrange the equations.

$$\begin{aligned}
A_0^f &= \frac{M_{0D}}{q} - A_{1D} + A_1, \\
A_0 &= A_{1D} + A_{0D} - A_1, \\
A_1^f &= \frac{M_{1D}}{q} + A_{1D} - A_1.
\end{aligned} \tag{8}$$

As A_1, A_0, A_1^f and A_0^f must all be non-negative, it follows that the following condition must hold in equilibrium:

$$\min\left\{A_{1D} + A_{0D}, \frac{M_{1D}}{q} + A_{1D}\right\} \geq A_1 \geq \max\left\{A_{1D} - \frac{M_{0D}}{q}, 0\right\}. \tag{9}$$

There exists a continuum of equilibria where the equations (8) pin down the equilibrium values of A_0^f, A_0 and A_1^f given any A_1 fulfilling condition (9). In addition we know that in every equilibrium $M_1 = M_0 = 0$. $\square$

9.6 Proof of Proposition 3

Proof. We assume an equal stock of money with and without QE. With QE the total amount of money in the reverse repo facility is

$$V^f = 2(1-\mu)\bar{M} + (2\mu - 1)\bar{M} = \bar{M}.$$

This is strictly higher than the amount without QE given by $V^f = \mu\bar{M} - (1-\mu)q\bar{A} > 0$ if $\bar{M} \geq q\bar{A}$ and $V^f = (2\mu - 1)\bar{M} > 0$ otherwise (see the proof of Proposition 1).

Alternatively, we could assume a larger stock of money during QE, and it is straightforward to see that the result still holds. □

9.7 Proof of Proposition 4

Proof. Compared to the case without QE the surplus formula of the PD0 changes. It is

$$S_0 = (\phi\epsilon + \phi q)(A_{0D} - A_{0n}) + [\phi\epsilon + \phi(1+r_r)q]\,(A_0 - A_{0D}) + [\phi\epsilon + \phi(1+r_f)q]\,(A_0^f - A_{0n}^f) \\ + \phi(1+r_d)(M_0 - M_{0n}).$$

Analogous to the proof of Proposition 2, we insert the equilibrium quantities into the definition for the surplus (see section 6.2.1). This implies

$$S_1 = \phi(r_r - r_f)qA_{0D},$$
$$S_0 = \phi(r_f - r_r)qA_{0D}$$

if $M_{1D} \geq qA_{0D}$ and

$$S_1 = \phi(r_r - r_f)M_{1D},$$
$$S_0 = \phi(r_f - r_r)M_{1D}$$

if $M_{1D} < qA_{0D}$.

Inserting the surpluses into $S_1 = (1-\theta)(S_1 + S_0)$ (see section 6.2.1) yields the repo market rate $r_r = r_f$.

Lastly, we compare this interest rate to the one in the equilibrium without QE which is $r_r = \theta r_f + (1-\theta)r_d$ (see Proposition 2). We know that $r_d > r_f$. Therefore it follows directly that the interest rate in the equilibrium with QE is lower than in the one without. □