SVERIGES RIKSBANK
WORKING PAPER SERIES
402

The Liquidity of the Government Bond Market – What Impact Does Quantitative Easing Have? Evidence from Sweden

Marianna Blix Grimaldi, Alberto Crosta and Dong Zhang

May 2021

WORKING PAPERS ARE OBTAINABLE FROM

www.riksbank.se/en/research
Sveriges Riksbank • SE-103 37 Stockholm
Fax international: +46 8 21 05 31
Telephone international: +46 8 787 00 00

The Working Paper series presents reports on matters in
the sphere of activities of the Riksbank that are considered
to be of interest to a wider public.
The papers are to be regarded as reports on ongoing studies
and the authors will be pleased to receive comments.

The Liquidity of the Government Bond Market – What Impact Does Quantitative Easing Have? Evidence from Sweden[§]

Marianna Blix Grimaldi[*], Alberto Crosta[†] and Dong Zhang[‡]

Sveriges Riksbank Working Paper Series

No. 402

May 2021

Abstract

We consider the effects of quantitative easing on the liquidity of the Swedish government bonds. To capture multiple dimensions of liquidity we use several measures built on a unique and highly granular transaction-based dataset. We find that the Riksbank's purchases of government bonds improved liquidity, but only to a point. In fact, the deterioration in the level of market liquidity from quantitative easing via the *scarcity effect* is significantly larger than the improvement from the *demand effect*. We find that such effects are *nonlinear*; they tend to be amplified when the share of the central bank holdings is larger than a threshold (40 percent).

Keywords: Market Liquidity, Government Bond Market, Quantitative Easing, Public Debt Management.

JEL Classification: E52, E58, G12.

[§]We would like to thank for comments from Mikael Apel, Meredith Beechey, Magdalena Belin, Johan Berg, Mårten Bjellerup, Cristina Cella, Mats Filipsson, Henrik Erikson, Klas Granlund, Johanna Hirvonen, Lars Hörngren, Jens Iversen, Reimo Juks, Nikita Koptyug, Jonas Niemeyer, Mattias Persson, Göran Robertsson, Anna Sjulander, Ulf Söderström, Xin Zhang as well as conference participants at the OECD PDM Conference 2019, CEMA meeting Rome 2019 and seminar participants at the Swedish National Debt Office, the Riksbank and the Swedish Financial Supervisory Authority. We are much indebted to Jörg Hofmeister for numerous discussions and contribution to analyzing the Swedish government bond market. Love Eklund provided excellent research assistance.

The opinions expressed in this article are the sole responsibility of the authors and should not be interpreted as reflecting the views of the Swedish National Debt Office, the Swedish Financial Supervisory Authority (Finansinspektionen) or Sveriges Riksbank.
[*] Swedish National Debt Office and Riksbank. Marianna Blix Grimaldi was visiting the Research Division of the Riksbank when completing the paper. marianna.blixgrimaldi@riksgalden.se.
[†] Swedish Financial Supervisory Authority. alberto.crosta@fi.se.
[‡] Dong Zhang worked at the Swedish Financial Supervisory Authority when working on the paper. E-mail: dong.zhang.cn@outlook.com.

1 Introduction

Following the 2008 global financial crisis (GFC), many economies have been faced with persistently low inflation. Even with monetary policy rates at historically low levels for prolonged periods, inflation rates have remained below the central banks' targets. In the last decade, these developments have significantly tested the conduct of monetary policy. Central banks have are using new tools for monetary policy, such as asset purchase programs (BIS, (2019)). Large-scale asset purchases (LSAPs), otherwise known as quantitative easing (QE), were first used by Bank of Japan in 2001 with the aim of stimulating the economy when the policy rate was already close to zero.[1] QE was also conducted during the GFC and its aftermath to address financial market disruptions. When financial markets stabilized, central banks continued to use QE with the aim of stimulating demand to increase inflation to target level in an environment of simultaneously low inflation, ample spare capacity and low interest rates.

Yet, after a decade of experience with QE policies, neither their effectiveness nor their potential unintended side effects are fully understood (BIS, (2019a)). The consensus is that QE, deployed as a tool for addressing financial market disruptions, has helped central banks to support the economy by preventing the economic outlook from deteriorating further as the GFC broke out, and thereby helping the recovery (BIS (2019b)).[2] But outside periods of crisis the effects of QE are much less understood and comparably little analyzed. As central banks continue to pursue their objectives by using QE programs, market participants have increasingly voiced concerns on the undesired consequences of QE (BIS (2019b)). Based on a survey of central bank governors and academics, Blinder et al. (2017) find that there is scepticism about the usefulness of keeping QE programs in the monetary policy toolkit due to the uncertainty about their costs and benefits. Williamson (2016) argues that QE has been ineffective in raising inflation. In a meta-analysis, Di Casola (2021) finds that the average effects of central bank balance sheet policies on inflation and output are positive, but there is significant variation in the effects measured in different studies. The early 2020 onset of the COVID-19 pandemic crisis unsettled financial markets and unhinged economies worldwide. To mitigate the economic fallout of the crisis and support their economies, central banks expanded their QE programs even further.

Given these developments, more research into the effects of central bank QE is needed. Our work contributes to the discussion about the central bank QE programs by studying the effects

[1] https://www.frbsf.org/economic-research/publications/economic-letter/2001/november/quantitative-easing-by-the-bank-of-japan/
[2] See among others Krishnamurthy and Vissing-Jorgensen (2011), Gagnon, Raskin, Remache, Sack. (2011) and Joyce, Lasaosa, Stevens and Tong (2011), De Santis (2016).

of the QE program of Sweden's central bank, the Riksbank, on government bond market liquidity.

The Riksbank QE program provides a compelling setting to evaluate the effect of central bank asset purchases. Under its QE program, the Riksbank purchased approximately 350 billion Swedish kronor (about 35 billion euro) worth of government bonds between February 2015 and April 2020, the end of the period we analyze. By mid-2017 the central bank owned about 40 percent of the outstanding volume of nominal government bonds, which form the bulk of the QE program, and one fifth of outstanding volume of the inflation-linked bonds. By April 2020, it owned more than half of the outstanding volume of nominal bonds and about one-fourth of the inflation-linked ones, an ownership share that stands out among the largest of major central banks using QE.[3] In addition, the Swedish government bond market is well established in an economy with a relatively low public debt. Swedish bonds are also among a handful of government bonds that have the highest credit rating. In contrast to other central banks, the Riksbank's QE program targeted only government bonds in the period we analyze.[4] This is an advantage in terms of analysis as it excludes potential spillover effects from purchases of other types of securities.

In this study, we use a rich and granular dataset based on Markets in Financial Instruments Directive (MiFID) transaction data at bond level. This allows us to use information from actual transactions for the government bonds. By using MiFID transaction data, we can compute several measures of liquidity, including those based on transaction prices. We contribute to the existing literature on QE by presenting a more complete picture of market liquidity compared to previous studies where liquidity measures are mainly based on aggregate data. Finally, our dataset extends from January 2012 to end of April 2020. To our knowledge, this is the longest period that has been analysed in this line of research. We are not aware of any other study on the effects of QE that employs MiFID transaction data to such extent.

We find that the Riksbank's purchases of government bonds improved liquidity, but only to a point. Crucially, the central bank's holding ratio, the volume purchased by the Riksbank in relation to the bond's total outstanding amount, plays a key role. We show that the impact from an increase in the holding ratio is *nonlinear* and that when above a certain threshold it tends to outweigh the positive impact from outright purchases. In particular, after a cut-off point, market

[3] The ECB, for example, has multiple QE programs targeting also corporate bonds but the purchase of government bonds was limited to 25% of each bond issuance originally in 2015, which was later increased to 33%. See https://www.ecb.europa.eu/mopo/implement/app/html/pspp-qa.en.html.

[4] It was only in March 2020, few weeks before the end of our sample period April 2020, that the Riksbank announced that it would extend its asset purchases to inter alia Swedish mortgage bonds. These purchases are aimed at keeping interest rates in general at a low level and contributing to an efficient supply of credit during the corona pandemic.

liquidity deteriorates. Importantly, the *nonlinearity* of the impact of QE on market liquidity may explain why the empirical literature on the impact of QE on government bond market liquidity has found mixed results.

We show that the central bank QE has also a significant impact on the usage of security lending facilities by primary dealers, absent which the negative impact of bond scarcity would presumably have been higher.

Our results show that there are side-effects of QE when the central bank becomes a large holder of the securities purchased through QE. The consequences we document in this paper are based on government securities, but the implied consequences of QE can easily extend beyond the strict precinct of the government bond market.

The remainder of the paper proceeds as follows. Section 2 reviews previous evidence on market liquidity and impact of QE. Section 3 provides background information on the Riksbank QE program. Section 4 describes the liquidity measures we compute and the theoretical underpinnings of those metrics. Section 5 describes our empirical strategy and the results. Section 6 concludes.

2 Previous work on QE and market liquidity

The relation between the QE programs and market liquidity is not clear *a priori.* Asset purchases are likely to stimulate trading by increasing the overall demand of the bond. On the other hand, the fact that asset purchased are often held until maturity, as it seems to be the case for most central banks, it reduces the quantity of assets that are available for trade for other investors, increasing search frictions and reducing liquidity.

The empirical literature has found both positive and negative effects of QE programs on market liquidity. Kandrac and Schlusche (2013) study the flow effects of the Federal Reserve (FED)'s large-scale asset purchase (LSAP) programs by looking at bid-ask spreads - a proxy for liquidity - of Treasuries, but do not find any significant results. Thus, they conclude that QE purchases had no effect on the functioning of the Treasury bond market. They do not study the persistent effects (also called *stock effects* or *scarcity effect*s) of LSAP announcements. Kandrac (2018) finds that the FED mortgage-backed securities purchases after the first round of QE have had a negative impact on some indicators of market functioning and in particular on liquidity conditions.[5] He does not find evidence though that the deterioration in liquidity impaired price

[5] From 2008-2015, the FED executed three rounds of QE, purchasing trillions in government bonds and mortgage-backed securities. By year end 2015, the FED had purchased securities for a value of 4.5 trillion USD.

discovery. Christensen and Gillan (2017) find that QE improved the liquidity in the TIPS (Treasury Inflation Protected Securities) market by temporarily increasing the bargaining power of sellers in the market. De Pooter and others (2018) find that the Securities Market Program (SMP) - large-scale asset purchases of sovereign debt from member nations - adopted by the European Central Bank (ECB) between May 2010 and September 2012 reduced the liquidity premia of the purchased sovereign bonds, supporting their market liquidity. D'Amico and King (2013) find that market liquidity on the US government bond market improved thanks to the Treasury LSAP program.

On the other hand, Han and Seneviratne (2018) find evidence of a deteriorated liquidity of the Japanese government bonds due to *scarcity effects* of the QE of the Bank of Japan. Pellizzon et al. (2018) find that the bid-ask spread increased through a *scarcity effects* but that it fell following outright purchases of the central bank.[6]

Similarly to our paper, Schlepper et al. (2017) use transaction-level data to measure market liquidity on government bonds. In particular, they find evidence of *scarcity effects* for the German government bond market (Bund) and that the ECB/Eurosystem public sector purchase program had an adverse impact on liquidity conditions in the Bund market. Missing from their analysis is an assessment of whether, overall, the net impact of the QE on market liquidity is negative or positive.[7]

Ferdinandusse, Freier and Ristiniemi (2020) build a search-and-matching theoretical model to understand the channels through which central banks' asset purchase impact yields and market liquidity. Close to the results of our paper, their theoretical model predicts a positive liquidity effect from central banks' purchases and a negative liquidity effect when market participants are crowded out from the market by the central bank. Crucially, their results depend on the share of preferred habitat investors and the level of liquidity prevailing in the market.

On a final note, recent evidence shows that during the COVID-19 outbreak in March 2020, the liquidity of the U.S. Treasury securities market deteriorated significantly but it also improved notably thereafter, reaching a level similar to those prevailing before the start of the pandemic (Fleming and Ruela (2020)).[8] Similarly, Crosta and Zhang (2020) show that the negative impact

[6] They proxy liquidity by the Corwin-Schultz bid-ask spread, which uses the information from daily high and low prices.
[7] The literature on the impact of QE on corporate bond market liquidity is scarce but rapidly increasing, see for example Boneva, Islami and Schlepper (2021) and references therein. The aforementioned literature shows mixed results.
[8] Fleming and Ruela (2020), at https://libertystreeteconomics.newyorkfed.org/2020/04/treasury-market-liquidity-during-the-COVID-19-crisis.html.

of the pandemic crisis on market liquidity for the Swedish government nominal bonds was only temporary and liquidity quickly returned to its pre-pandemic level.[9]

3 The Riksbank's QE program

The Riksbank began its QE program in February 2015 by announcing that it would purchase government bonds for an amount of 10 billion SEK.[10] After this first rather modest purchase, the amount of government bonds bought by the central bank increased substantially and quickly. In March, April and July 2015 more government bonds were purchased for a further total amount of 125 billion.[11] In October 2015, the Riksbank announced that it would increase purchases of government bonds by 65 billion SEK and that the planned total purchased volume would amount to 200 billion SEK by the middle of 2016, equalling about 30 percent of the then outstanding stock of Swedish government bonds and approximately 5 percent in terms of GDP[12].

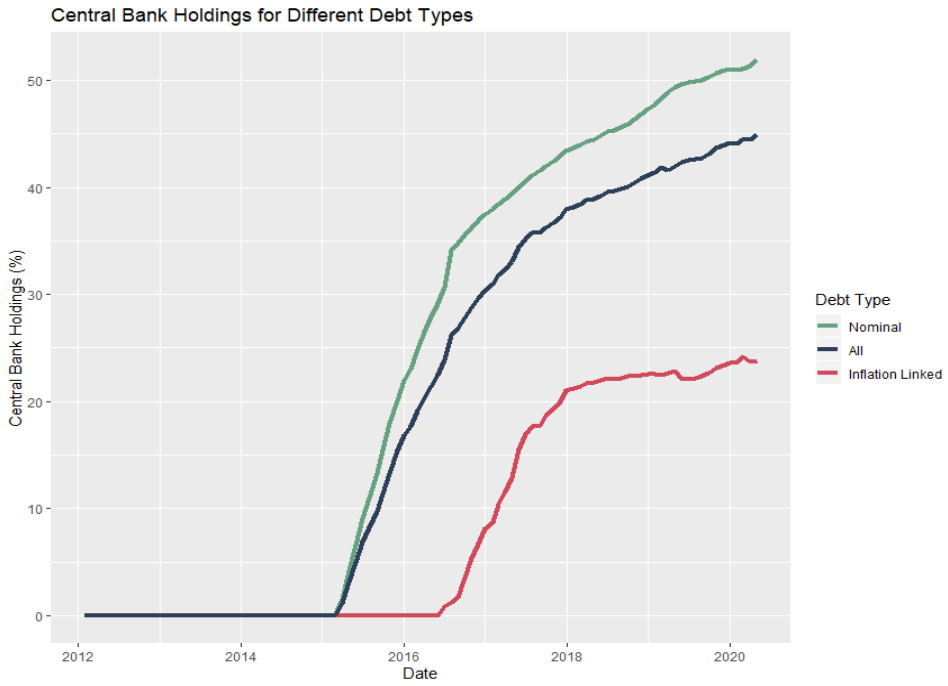
In April 2016, the Riksbank added 45 billion SEK to its purchases. The purchases covered both nominal and inflation-linked bonds, for a corresponding amount of 30 and 15 billion SEK. In December, it decided to continue purchasing both nominal and inflation-linked bonds by a further combined 30 billion SEK, bringing the total to 275 billion SEK.[13] In April 2017, the total amount increased to 290 billion SEK.[14] During 2018, reinvestment purchases of coupons and bonds that had reached maturity for about 60 billion SEK were the *only* source of the Riksbank demand. The reinvestments continued until the central bank announced at its monetary policy meeting in April 2019 that it would buy a further 45 billion SEK of government bonds. It also specified that amount was half of the correspondent value of maturing bonds and coupon payments and that the purpose of the purchases was to maintain an appropriate level of holdings and the Riksbank's presence in the market.[15] At that time, the total amount held was 316 billion SEK in nominal terms. Finally, in March 2020, as a response to the economic crisis

[9] They also show a similar pattern for Swedish covered bonds during the COVID-19 crisis. Compared to sovereign nominal bonds, market liquidity for Swedish covered bonds improved slightly during the 2012-2020 period.
[10] The Riksbank started to buy government bonds before the announcement in February. This was done for technical reasons and the amount was very limited.
[11] More specifically, in March the Riksbank decided to buy 30 billion of government bonds and lower the policy rate to -0.25 per cent. In April announced purchases of a further 40-50 billion and kept the policy rate at -0.25 per cent. It lowered the policy-rate path significantly signaling that more cuts to the policy rate were possible. In July, it decided to cut the policy rate by 0.10 percentage points to -0.35 per cent and to extend the purchases of government bonds by a further 45 billion.
[12] See http://archive.riksbank.se/sv/Webbarkiv/Publicerat/Pressmeddelanden/2015/prm151028/index.html. The Swedish GDP for 2016 is approximately 4400 billion SEK.
[13] Nominal and inflation-linked bonds were decided to be purchased in equal amount of 15 billion SEK respectively. The Riksbank also announced a policy of reinvestment of coupons and bonds that had reached maturity. The total amount of 275 excludes that reinvestment for a value of around 30 billion.
[14] The total amount of 290 billion SEK excludes reinvestment of coupons and bonds that had reached maturity. The Riksbank also announced that reinvestments would continue until further notice.
[15] See https://www.riksbank.se/en-gb/press-and-published/notices-and-press-releases/press-releases/2019/repo-rate-unchanged-at-02.25-per-cent/.

caused by the COVID-19 pandemic, the Riksbank announced that it would purchase additional securities up to 300 billion SEK. Under this pandemic-related program, the central bank committed for the first time to buy securities other than government bonds for monetary policy purposes. The total amount held in February 2020, at the start of the pandemic crisis, was about 335 billion SEK.

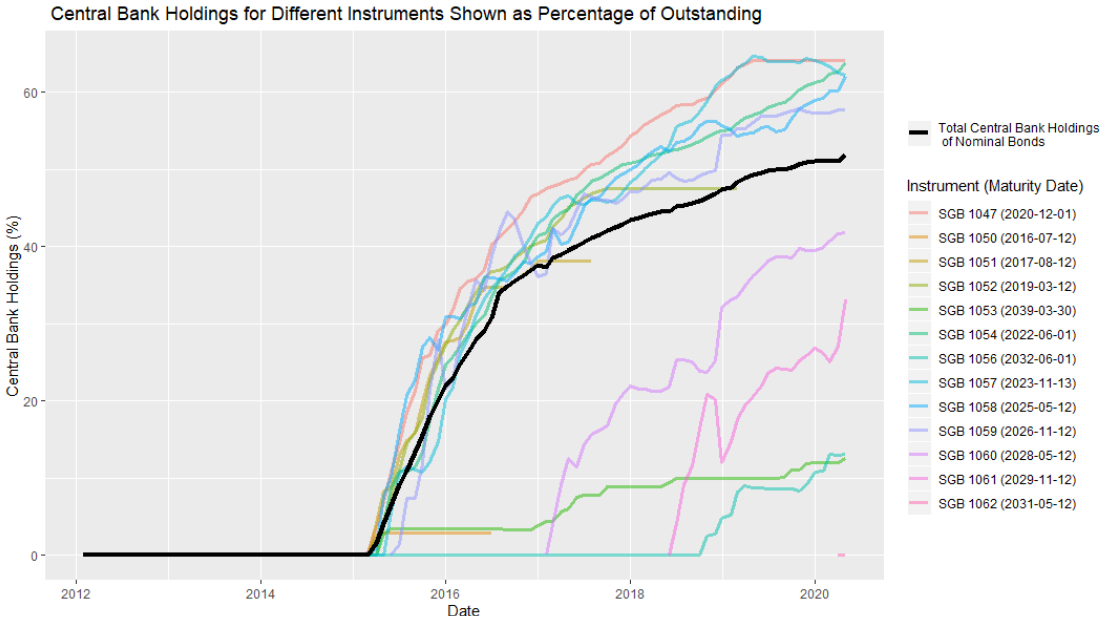
Between February 2015 and April 2020, the Riksbank's holdings as a share of the total outstanding rose quite rapidly, as Figure 1 shows. The Riksbank purchased mostly nominal bonds, and the purchased amount differed significantly from bond to bond and by maturity group over time. Some bonds were purchased quite a lot more and their associated Riksbank's holding share reaches more than 60 percent (Figure 2).

Figure 1. Riksbank's holdings of Swedish government bonds



Note: The figure above shows the Riksbank's holding of the Swedish government bonds. The holding is the weighted average (by outstanding amount) per month and bond type. Nominal, Inflation-Linked and All indicate the nominal bonds, inflation linked bonds and both bond types, respectively. The studied period is between February 2015 and April 2020.

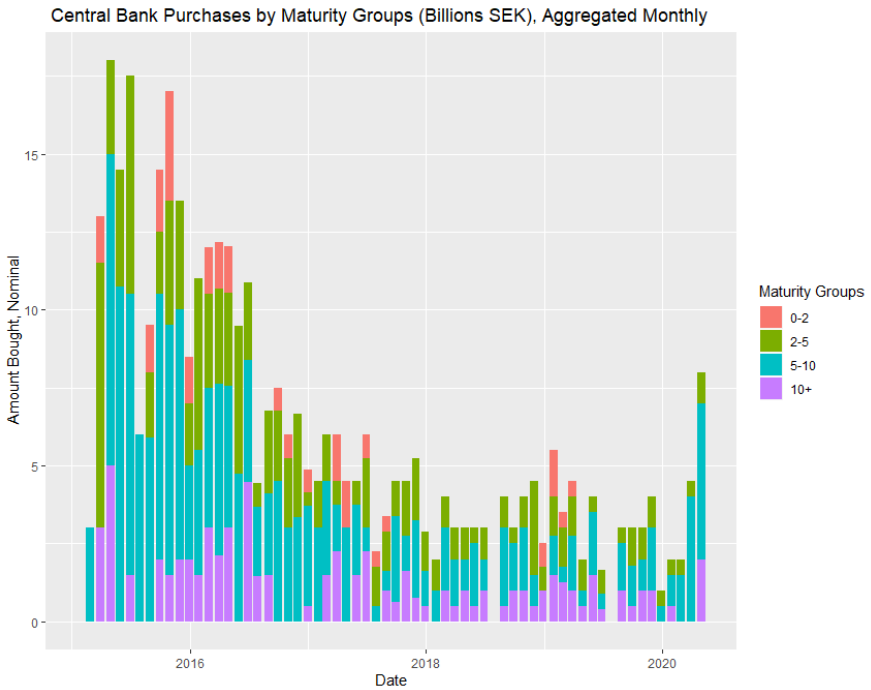
Figure 2. Ownership share by the Riksbank, by bond



Note: Figure 2 shows the Riksbank's ownership share of nominal bonds, by bond. The black line is the total amount of nominal bonds weighted by total outstanding amount. The period is between February 2015 and April 2020.

Initially, most of the volume bought was of bonds with a time to maturity from 1 up to 5 years (Figure 3). As the total volume bought increased rapidly and bonds with the shortest maturity were redeemed, the Riksbank purchased bonds with longer maturities resulting in a relatively stable share of purchases and holdings by maturity (Appendix I).

Figure 3. Purchases by maturity



All purchases under the QE program were made through solicited bids from the central bank's monetary policy counterparties, as well as the Debt Management Office (DMO)'s primary dealers via auctions.[16] In the period covered by this analysis, the Riksbank conducted a total of 265 auctions, once every week on average. The Riksbank purchased only one type of bond on a specific date, which means that it never purchased nominal bonds and inflation-linked bonds on the same day. Moreover, bonds of the same type were never bought on two different dates during the same week. A summary of Riksbank's purchases is presented in Table 1.

Table 1. Summary statistics of the Riksbank's purchase

	Nominal bonds	**Inflation-linked bonds**
First purchase date	26/02/2015	21/04/2016
Last purchase date (in our sample)	30/04/2020	13/03/2020
Total Purchased amount (billion SEK)	381	49
Number of purchases	397	126
Min purchase (billion SEK)	0.2	0.1
Max purchase (billion SEK)	3.5	0.8
Number of unique bonds purchased	12	8
Number of purchase dates	202	63
Median purchase size (% of outstanding amount)	1.0%	1.4%
Average purchase size (% of outstanding amount)	1.5%	1.8%
Max purchase size (% of outstanding amount)	10.0%	7.8%

The Riksbank was transparent ahead of each auction. Its statements specified which bonds would be purchased, the maximum tendered volume and the minimum and maximum volumes that could be offered, together with details about day and time of the auction procedure. Subsequently, after each auction and on the same day of the auction it also made public the volume offered and bought, the number of bids offered and accepted, the average yield and how the amount of the purchases was distributed among bidders. Figure 4 (Panel A) shows an example of a typical auction announcement and (Panel B) of a typical announcement of an auction results.

[16] The bid procedure is a multiple price method with differentiated pricing on allocation.

The Riksbank's purchases never took place in direct connection with the DMO's auctions on the primary market and the central bank did not purchase bonds that were newly issued. The stated motivation of such a policy was to minimize the risk of potential distortions in the bond price formation and, at the same time, to address monetary financing concerns.[17]

Figure 4. Announcement of QE by the Riksbank

Panel A

	BID PROCEDURE 28 NOVEMBER 2019
Bonds	Government bond SGB 1058 (SE0005676608) Government bond SGB 1061 (SE0011281922)
Bid date	Thursday 28 November 2019
Bid times	0900-1000 hours (CET) on the Bid date
Requested volume (corresponding nominal amount)	SEK 500 million ± SEK 250 million in issue SGB 1058 SEK 500 million ± SEK 250 million in issue SGB 1061
Highest permitted bid volume (corresponding nominal amount)	A maximum of SEK 500 million per bid in issue SGB 1058 A maximum of SEK 500 million per bid in issue SGB 1061
Lowest permitted bid volume (corresponding nominal amount)	SEK 50 million per bid
Expected allocation time	No later than 1010 hours (CET) on the Bid date
Delivery and payment date	Monday 2 December 2019
Delivery of Bonds	To the Riksbank's account in Euroclear Sweden AB's securities settlement system 1 4948 6383

Stockholm, 22 November 2019

Panel B

Auction	Result of auction SEK Bonds
Auction date	2019-05-16
Loan	1054
ISIN-code	SE0003784461
Coupon	3.50 %
Maturity	2022-06-01
Tendered volume, mln SEK	500 +/- 250
Volume offered, mln SEK	2,450
Volume bought, mln SEK	500
Number of bids	7
Number of accepted bids	1
Average yield	-0.529 %
Lowest accepted yield	-0.529%
Highest yield	-0.529 %
% accepted at lowest yield	100.00

Note: Figure 4 presents the announcement of the government bond purchase in the QE program by the Riksbank. Panel A is an announcement of the bid procedure before an auction, and panel B is the result of an auction.

4 Liquidity measures for the government bond market

Market liquidity reflects how quickly and easily a security can be traded at a price close to the market price just before the transaction takes place.[18] If market liquidity is good, the holder of an asset can convert it into cash quickly, in large volumes, at a low transaction cost, and with little impact on the price even under stressed market conditions.

Due to its characteristics, market liquidity is not directly observable. Instead, the academic literature commonly identifies five different dimensions to describe liquidity: tightness, immediacy, depth, breadth, and resilience (see Sarr and Lybek (2002)). *Tightness* relates to

[17] M*onetary financing* refers here to the notion of money creation as permanent source of financing for government spending. See http://archive.riksbank.se/en/Web-archive/Published/Press-Releases/2016/The-Riksbank-will-not-be-participating-in-the-Swedish-National-Debt-Offices--exchanges/index.html.

[18] Modern finance distinguishes between market liquidity and funding liquidity. More recently, the International Monetary Fund (IMF, 2015) describes three different types of liquidity: funding liquidity, market liquidity and monetary liquidity.

transaction costs.[19] *Immediacy* mainly refers to the speed at which orders can be executed, which means that the shorter the time, the higher the liquidity, all else equal.[20] Market makers are an important source of *immediacy* since they set the bid and ask prices at which other market participants' trade. *Depth* refers to the existence of orders and trade interest at prices beyond the best buy and sell orders. The market is considered *deep* when there is abundance of buy and sell orders and a constant interest in trading. *Breadth* refers to the volume of orders and interest in trading.[21] Finally, *Resiliency* refers to the ability of the prices to quickly recover from trade imbalances that tend to move the price away from its fundamental levels.

Each of these five dimensions can be indirectly measured using different liquidity indicators. The choice of the liquidity measures depends on both the type of the financial asset and the market where it is traded. For instance, liquidity can be affected by the residual time to maturity of an asset, as in the case of bonds, or by the presence (or absence) of an order-book driven market with readily available bid and ask quotes. Moreover, some measures are more suited to assets that trade frequently, such as government bonds and stocks, while others are appropriate to measure liquidity of assets that are traded less frequently, as in the case of most corporate bonds in Sweden.

Another and perhaps even more compelling problem in estimating liquidity is data availability. For most assets traded over-the-counter (OTC), the information available via commercial databases is mostly limited to aggregated data on traded volumes, and in some cases to noisy bid-ask spreads which can vary substantially across data providers. This significantly hampers the possibility to measure and analyze market liquidity.

To overcome the data availability problem, in this paper we use a novel and granular set of data based on transaction reports under Markets in Financial Instruments Directive (MiFID-I) and Markets in Financial Instruments Directive II (MiFID-II) regulations.[22] Transaction data allow us not only to use the detailed post-trade information included in every single transaction at intraday frequency, but also makes it possible to compute an extensive set of liquidity measures. In particular, we calculate five of the liquidity measures presented in Crosta and Zhang (2020). The five measures are chosen to cater for the characteristics of the Swedish government bond

[19] Transaction costs are often proxied by quoted bid-ask spreads (pre-trade information) or estimated using transaction prices (post-trade information).
[20] According to Sarr and Lybek (2002), in addition to the speed of execution, immediacy can even reflect the speed of settlement, which means immediacy measures the efficiency of trading, clearing and settlement systems.
[21] As an illustration of depth and breadth, a liquid order book market contains large volumes of orders (high in breadth) at many different price levels from the best buy and sell prices to prices deeper in the order book (high in depth).
[22] See Data section and Appendix II for more information.

market in this study. For instance, we exclude the indicators Zero Trading Days (ZTD) and Non-Trading Instruments (NTI) as almost all nominal government bonds in our study are traded every day, which means that these two measures would not capture any change in market liquidity. We briefly describe the liquidity measures below and leave the detailed description to Appendix II:

- Total trading volume per day (*TURN*) describes the total volume traded on each bond per day. A low turnover is a sign of low liquidity, since it indicates that it might be difficult to trade large volumes.
- Turnover ratio (*TR*) for a bond is the share of the total outstanding amount that is traded on a specific day. When turnover ratio is high, liquidity is high as turnover on a bond is large with respect to its outstanding amount. On the other hand, whenever large shares of a bond are held by some market participants, liquidity might decrease as the amount available for trading, the *free-float*, in that specific bond is reduced.
- Yield impact (*YI*) is a modified version of the original Amihud's price impact (Amihud (2002)) which is a proxy for the bid-ask spread, and can be described as a measure of the cost of a transaction expressed in yields to maturity. All else equal, the higher the yield impact, the more expensive it is to trade a specific bond, which means that liquidity is lower.
- The Market Efficiency Coefficient (*MEC*) proposed by Hasbrouck and Schwartz (1988) measures market resiliency by looking at the ratio between volatility of short-term and long-term returns. The assumption is that in resilient markets new information is quickly incorporated in prices, which means that volatilities of long and short-term returns tend to converge when markets are resilient.
- Volume-adjusted intraday volatility (*VAIV*) is a price- and turnover-based indicator that measures how the price of a security moves over one day in relation to the volume that is traded during that day. Therefore, volume-adjusted intraday volatility considers how liquidity is reflected in both the prices and the traded volumes. A high value of VAIV means low liquidity.

We aggregate the data at weekly frequency to reduce unduly noise from daily data. We compute such measures on all nominal and inflation-linked Swedish government bonds in the period January 2012-April 2020. Table 2 shows a summary of the characteristics of the liquidity measures we compute. Note that, in general, each liquidity measure captures primarily one

dimension of liquidity, but it can also describe other dimensions indirectly. In Appendix II we show them graphically and report some related basic statistics.

Table 2. Individual liquidity indicators and their characteristics

Indicator		Category	Dimension	Direction
Turnover per day	TURN	Turnover-based	B, D, I	+
Turnover ratio	TR	Turnover-based	B, D, I	+
Yield impact	YI	Price-based	T	-
Market Efficiency Measure	MEC	Price-based	R	-
Volume-Adjusted Intraday Volatility	VAIV	Price- and Turnover-based	B, D, T, R	-

Note: *Category* refers to the information/variable the indicator is based on. *Dimension* refers to the dimensions primarily captured by the indicators. The dimensions are tightness (T), immediacy (I), depth (D), breadth (B) and resilience (R). *Direction* describes whether a higher value in a liquidity indicator in its original version indicates a higher level of liquidity, everything else being equal. "+"/ "-" means that a higher value of the indicator reflects a higher (lower) liquidity level.

5 The DMO's securities lending facilities

As part of its financing strategy, the Swedish DMO operates a security lending facility (SLF). The primary aim of the SLF is to contribute to the liquidity of the Swedish government debt and support the smooth functioning of short-term funding markets. The facility is demand driven which means that it is offered to the DMO's counterparties when they demand so, regardless of the bond outstanding volumes.

The Swedish DMO's SLF consists of a *repo facility* and a *repo swap facility*.[23] In the *repo facility*, government securities – usually bonds – are traded overnight (ON) or for two business days (T/N) at a set price.[24] The DMO has conducted ON and T/N reverse repos daily since 2000. As of 2004, it also manages a *repo swap facility*, where government bonds can be swapped for another government security, typically government bills, at a set price with the swap having one-week maturity and being cash-neutral.

The DMO provides its *repo facility* for repurchases agreements to its primary dealers. In a repo transaction, a party sells government debt securities to a counterparty subject to an agreement to repurchase the securities later at an agreed price. Repos are economically similar to a

[23]In general terms, a SLF can be of different types (World Bank (2015)). In Sweden, the facility is operated as a sell/buy-backs facility. This means that the DMO sells the security and buys it back at a specified later date with all owner rights transferred to the buyer, i.e. a transaction is based on two separate legal agreements (a buy and a sell agreement).

[24] In the period covered by this study – January 2012 to April 2020 – the price for the ON and T/N facility was set at the monetary policy rate (i.e. the *repo rate*, the rate of interest at which banks can borrow or deposit funds at the Riksbank for a period of seven days) minus 45 and 40 basis points respectively. For the swap facility, this price was 30 basis point below the monetary policy rate. In January 2020 it was changed to the monetary policy rate minus 20 basis points.

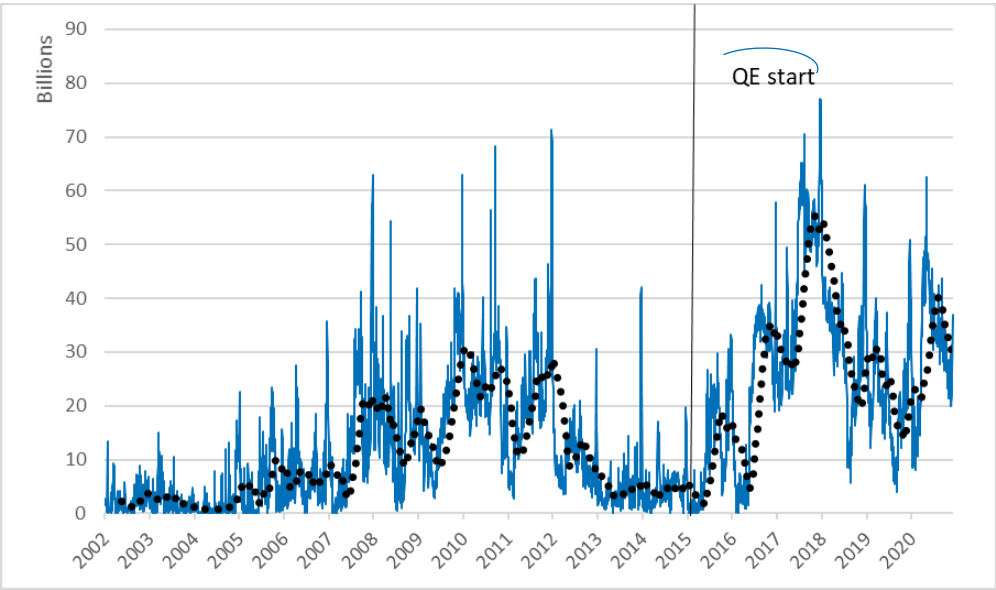
collateralized loan. The DMO repos provide specific securities to the primary dealers requesting them.

In practical terms, the arrangements of the SLF allow primary dealers to borrow any bond from the DMO, in *unlimited* size up to two business days. In the *repo swap* facility there is a maximum volume that can be transacted. Both facilities come with the option of *rolling-over* the transactions *indefinitely*.

The DMO's primary dealers are the only dealers who can participate in the SLF. This exclusive participation agreement allows dealers to get hold of bonds outside the regular securities auctions in the primary markets. In exchange, the dealers are expected to submit bids that are reasonable in terms of market pricing at the time of the auction in all government securities auctions and quote buy and sell prices in the secondary market. In order to be eligible as primary dealer, dealers have to comply with a set of requirements, for example they need to maintain a market share that it is at least 2.5% of the total turnover on the primary market at every auction. Once dealers become primary dealers, they are expected to continue to meet the DMO expectations and eligibility criteria on an ongoing basis.

An apparent paradox of a SLF is that it is "best used when little used". The rationale is that the facility is intended to be a last resort mechanism. Primary dealers are expected to first try to cover their positions by borrowing securities from the market. A SLF provides only a safety net: if dealers encounter a delivery problem or need to cover (or create) a sell position in the market and cannot meet their commitments, the DMO provides for the missing securities via a repo or a repo swap transaction. In this way, the DMO acts as a "securities lender of last resort".

Figure 5. The usage of the SLF over time



Note: The SLF volume in Figure 5 is the sum of the volumes of nominal bonds repoed out in the facility.

The usage of the DMO's facility has increased significantly after the Riksbank launched its QE programs. Figure 5 shows that the volumes of bonds created in the facility and repoed out to the primary dealers from 2002 to 2020. The volumes reached 60 billion during 2017, an all-time high. They declined somewhat after 2017, but they remained at a level significantly higher than the average level before the QE period. This unusually high usage of the facility is likely to be related to bond *scarcity*. As the so-called *free float* - that is the amount of bonds that is available for trade for private investors - diminishes, the primary dealers resort more to the SLF to avoid fail-to-deliver and be able to continue to fulfill their market-making commitments. Survey data from the DMO provide supportive evidence of a scarcity-induced usage of the SLF and the role of the SLF in mitigating falling free-float.[25]

The SLF is not the only tool the Swedish DMO's uses to promote liquidity in the secondary government bond market. It also uses *switches* from time to time. *Switches* are a common tool among DMOs and are typically used for achieving several goals within the debt management (Blommestein, Elmadag and Ejsing (2012)). In a *switch* operation a DMO gives the opportunity to investors to exchange existing bonds - typically less-liquid and off-the-run - with newly issued bonds having higher liquidity.

[25] See https://www.riksgalden.se/globalassets/dokument_eng/press-and-publications/reports/evaluation-central-government/central-government_management_-basis_for_evaluation_2018.pdf.

The Swedish DMO uses *switches* mainly for building-up the volume of selected bonds more quickly.[26] In the past, it has also used *switches* to concentrate liquidity across the yield curve by consolidating issuances into larger and more liquid maturities. This was done, for example, at times of declining public debt and significantly reduced issuance needs (SNDO (2017)). *Switches* are performed through auctions whose terms and conditions are announced well in advance, up to 4 weeks - to give investors time to adjust with a large margin.

While enhancing liquidity on the government bond secondary market is not a primary objective of the DMO, it is worth to note that the DMO's operations promote secondary market price efficiency and aims at reducing the government's interest rate expenses.

6 Data and empirical strategy

6.1 Data

In order to compute the liquidity measures, we use a novel and comprehensive confidential database based on transaction reporting under the Markets in Financial Instruments Directive (2004/39/EC), more commonly known as MiFID I, and the more recent directive (2014/65/EU), also known as MiFID II.[27] We obtain these data from the Swedish Financial Supervisory Authority (Finansinspektionen).

MiFID I came into force in January 2007 as a tool for national competent authorities (NCA) to detect and investigate potential market abuse. Under MiFID I,[28] all investment firms and credit institutions were required to report transactions involving financial instruments admitted to trading on a regulated market. The content of these transaction reports was then passed on to the national competent authority (NCA) of the most relevant market in terms of liquidity. In Sweden this is the Financial Supervisory Authority. In January 2018, MiFID II replaced MiFID I and widened the scope of application of the previous directive. MiFID II extended goals are, among others, to enhance investor protection, to monitor the fair and orderly functioning of the market, to achieve greater transparency and to promote market integrity. For this reason, transaction reporting under MiFID II has been extended to cover a wider set of instruments and information on each transaction reported to the NCAs, also including a broader group of

[26] See, for example, Terms for switches to new government bond SGB 1063 - Riksgälden.se (riksgalden.se)
[27] Directive 2014/65/EU was accompanied by the Markets in Financial Instruments Regulation (Reg. EU No. 600/2014), also known as MiFIR.
[28] Article 25(3) and (4) of Directive 2004/39/EC.

reporting firms. The content of transaction reporting is defined in specific regulatory technical standards drafted by the European Securities and Markets Authority (ESMA).[29]

Among others, the transaction reports under and MiFID I and MiFID II/MiFIR include the following data fields:

- Instrument identification code (ISIN)[30]
- Date and time of the trade
- Identifiers of buyer and seller (BIC or LEI)
- Price at which the trade was made
- Traded quantity
- Trading venue

Our dataset includes all transactions on Swedish government bonds from January 2012 to April 2020.[31] We use the transactions for the period January 2012 to December 2017 and the period January 2018 to June 2020 based on MiFID I and MiFID II reporting system respectively.[32] The raw data consist of 802,102 reported transactions, of which 640,739 are for nominal bonds and 161,363 are for inflation-linked bonds. We carefully filter our data following Crosta and Zhang (2020) filtering procedure in order to remove obvious errors, double transactions and split transactions among others. Our final sample amounts to 316,413 unique transactions, of which 260,948 on nominal bonds and 55,465 on inflation-linked bonds. A more extensive illustration of the filtering procedure is provided in Appendix II.

It is worth noting that trading of the Swedish government bonds was primarily organized as bilateral trading over the counter (OTC) until the coming into force of MiFID II regulation in 2018. Starting in January 2018, the transaction volume traded on electronic trading platforms has increased sharply. In 2019, approximately 60 percent of the trading in both government and covered bonds were carried out on a on an electronic trading platform, see Swedish Financial Supervisory Authority (2019).[33] The dataset used in this study contains all transactions regardless where the transactions took place.

[29] See for instance RTS 22 for what concerns a more detailed description of all fields included in transaction reporting: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0590
[30] As defined in ISO 6166.
[31] We exclude data prior to 2012 due to quality issues, see Crosta and Zhang (2020).
[32] MiFID I and MiFID II database include also transactions of foreign investors and therefore it is more comprehensive than other available dataset, including the Swedish Central Bank's SELMA database. See Crosta and Zhang (2020) for a discussion.
[33] MiFID II expanded the EU's existing transparency rules to include all financial instruments traded on a trading platform, including non-equity instruments (i.e. bonds, derivatives, structured financial products, and emissions allowances). The rules distinguish between the publication of pre-trade (order data) and post-trade (transaction data) information

Bond-specific data, data at daily frequency on issued amounts and data on the SLF volumes for each bond are provided by the DMO. All data related to the quantitative easing program of the central bank are downloaded from the website of the Riksbank. All other market data used in the analysis are from Bloomberg.

6.2 Empirical strategy

We examine the effects of QE on the different dimensions of market liquidity by estimating the following panel regression with bond and time (month) fixed-effects. We invert signs on *VAIV*, *MEC* and *YI* measures, so that a higher value of all five liquidity measures indicates a higher level of liquidity. The data is computed at weekly frequency.

$$Liq_{i,t} = \beta_0 + \gamma_t + \delta_i + \beta_1 Purchases_{i,t} + \beta_2 Holding_{i,t-1} + \beta_3 SLF_{i,t-1} + \beta_4 X_t + \varepsilon_{i,t} \quad (1)$$

where $Liq_{i,t}$ is the liquidity measure of bond i at time t. For a better comparison, we standardize all measures on a bond-by-bond basis. $Purchases_{i,t}$ is the amount purchased of bond i in the auction during week t relative to the total outstanding amount of that bond.[34] $Holding_{i,t-1}$ is the lagged value of the Riksbank relative holding ratio, measured as the government bond's volume owned by the Riksbank in relation to that bond's total outstanding amount. $SLF_{i,t-1}$ is the total volume of each bond that is either repoed or swapped in the DMO's SLF relative to the free float – defined as the total outstanding amount net of the central bank holding.[35] Notably, the SLF is mostly used when market liquidity is low and may be endogenous. We therefore use the lagged volume of the SLF to avoid endogeneity. In robustness checks, we perform regressions with up to four lags of the SLF and a regression with the SLF variable orthogonalized to mitigate potential multicollinearity. X_t is a vector of macro and financial variables we use as controls.

Our baseline regression includes also a sovereign bond market liquidity index computed by the European Securities and Market Authority (ESMA) based on domestic MTS data, see De Renzis, Guagliano and Loiacono (2018).[36] The ESMA sovereign bond liquidity index in our baseline model is meant to capture potential international spillovers in liquidity. We also include as a control variable the issued amount of each bond normalized by the bond

[34] The "week period" includes both the announcement day, the day of the purchases and all the days in between. The estimated impact of purchases in the analysis captures the *demand effect* from announcement to purchase and therefore it represents the overall demand effect we are after better than it would have if we would have included only the days of outright purchases. We explain the *demand effect* later in the section.

[35] Our computed "free float" is upward biased. A more precise measure of free float would be net of holdings of long term, buy-and-hold investors other than the central bank. We do not have data on the holdings of these investors.

[36] MTS is the largest wholesale interdealer platform for sovereign debt securities. It covers sovereign bonds for ten EU members.

outstanding amount. The assumption is that the larger the issued volumes, the higher the liquidity.

In our robustness checks we include in X_t the VIX index, a measure of liquidity premium (spread between Stibor TN and the monetary policy rate), the difference between the five and two-year government bond yields, the sovereign debt to GDP ratio, a Swedish business confidence indicator and the lagged ratio of issued amount of each bond to debt. We also change the ESMA's sovereign bond market liquidity index based on domestic MTS with the one based on Euro MTS.

Our hypothesis is that market liquidity increases following the outright purchases of the central bank. The demand of the central bank acts as a double-lifter for liquidity. First, the purchases directly increase liquidity by increasing trading. They also increase liquidity indirectly. Indeed, by clearly announcing the purchases details, the central bank commits to buy a predetermined nominal amount of those bonds (see Figure 4, Panel A). By doing so, it creates incentives for market participants to trade and hoard those securities that the central bank has committed to buy. It is worth noting that while the central bank aims at buying the bonds for a price as close as possible to the market price, it is likely to be relatively price insensitive. This *demand effect* indicates a positive relationship between the liquidity measures and the variable $Purchases_{i,t}$.

We also expect market liquidity to be a declining function of the holding ratio of the central bank. That is, the larger the share held by the central bank, the lower the market liquidity. Our hypothesis is that this negative relationship can be *non-linear*, which means that only above certain levels of holding ratio it becomes more significant. This *scarcity effect* on the government bond market has been documented for the QE programs of several central banks, among them the ECB (Ferdinandusse, Freier and Ristiniemi, (2020)) and Bank of Japan (Han and Seneviratne, (2018)).

The main results of our regression are presented in Table 3 (*Baseline*), where each column reports the results for our computed liquidity measures for nominal government bonds. We choose to exclude inflation-linked bonds from our baseline regression as they are issued in much lower volumes and are structurally much less liquid than nominal bonds.

Table 3. Main regression results

		TURN	*TR*	*VAIV*	*MEC*	*YI*
Baseline						
	$Purchases_t$	**8.55***	**9.92*****	**5.7*****	0.17	**4.44*****
		(4.98)	(3.84)	(2.18)	(3.68)	(1.48)
	$Holding_{t-1}$	**-0.99****	**-1.57*****	**-0.7*****	**-1.48*****	**-0.91*****
		(0.4)	(0.31)	(0.25)	(0.41)	(0.24)
	SLF_{t-1}	0.55	0.55	**1.04****	0.5	**0.93****
		(0.92)	(0.85)	(0.51)	(0.58)	(0.45)
Holding>= 40%						
	$Purchases_t$	**53.19*****	**54.54*****	**14.01*****	0.28	10.23
		(10.18)	(10.22)	(3.16)	(10.57)	(6.24)
	$Holding_{t-1}$	1.1	1.04	**-2.85*****	**-6.84*****	**-4.16*****
		(1.46)	(1.43)	(0.85)	(1.17)	(1.05)
	SLF_{t-1}	0.91	0.88	**0.66***	0.38	**0.68***
		(0.99)	(0.97)	(0.35)	(0.65)	(0.37)
Holding< 40%						
	$Purchases_t$	3.92	**5.68***	3.43	**-3.96***	1.37
		(4.98)	(3.43)	(2.99)	(2.32)	(2.32)
	$Holding_{t-1}$	-0.73	**-1.47***	-0.77	-0.05	-0.7
		(0.95)	(0.78)	(0.62)	(0.88)	(0.65)
	SLF_{t-1}	0.53	0.66	0.44	1.63	0.35
		(1.45)	(1.35)	(0.99)	(1.18)	(0.91)
Fixed effect		Yes	Yes	Yes	Yes	Yes
Controls		Yes	Yes	Yes	Yes	Yes
Adj. R-Squared						
Baseline		0.03	0.09	0.04	0.07	0.07
Hold. >= 40%		0.04	0.04	0.10	0.17	0.21
Number of Obs.						
Baseline		3939	3939	3688	3693	3907
Hold. >= 40%		986	986	949	985	985

Note: Fixed effects are time (month) and bond fixed effects. ***Controls*** include the issuance volumes normalized by the bond outstanding amount and the ESMA sovereign bond market liquidity index based on domestic MTS. Generally, both control variables are statistically significant and with the expected sign. The results in panel 2 (3) are from estimating our baseline model but on a subset of bonds for which the central bank's holdings are larger (lower) than 40 percent. *, **, *** denote a significance level at 90%, 95% and 99% respectively. Standard errors are in parenthesis. Data are aggregated at weekly frequency.

Results in Table 3 shows a positive *demand effect* of the QE on market liquidity, i.e. the Riksbank's purchases increase market liquidity. For four out of five liquidity measures the coefficients on outright purchases of the central bank are significant and positive.[37] One possible complication is that an endogeneity problem arises if the Riksbank's purchases are focused on bonds that happen to be particularly liquid at the time of the transaction.

To address this endogeneity concern we regress purchases of each bond on the bond liquidity that prevailed in the week before the Riksbank purchased the bond, i.e. we estimate $Purchases_{i,t} = \alpha_0 + \gamma_i + \delta_t + \alpha_1 Liq_{i,t-1} + \varepsilon_{i,t}$. We find no compelling evidence that the Riksbank' purchases were systematically driven by liquidity, although our results cannot exclude that, at times, the Riksbank may have cherry-picked or purchased the at-that-time most liquid bonds. We show the detailed results in Appendix IV.

Table 3 also shows that for all liquidity measures the coefficient for the holding is significant and negative. This result indicates a *scarcity effect* of QE, as the Riksbank's holding decreases market liquidity. The coefficients on holding are smaller than those on outright purchases. For example, for the *Yield Impact* (*YI*), which in the regression means a higher value of YI, indicates higher liquidity level, one unit increase in the outright purchases increases liquidity by about 4.4 standard deviations. The magnitude of the coefficient for the holding is five times smaller. However, the outright purchases are a one-time-event while holding is not. Indeed, the coefficient of $Purchases_{i,t}$ captures the effect of the Riksbank's purchase at time *t*, while the coefficient of holding captures the accumulated effect of all previous purchases. In fact the effect of holding lasts as long as the central bank holds the bond, i.e., *de facto* until its maturity. Therefore, the impact of the *scarcity effect* is more persistent than the *demand effect*.[38] As a practical example, a Riksbank's outright purchase of average size (approximately 1.5% of the outstanding amount) of a nominal bond is associated with an increase of *YI* by 0.03 basis points from an average level of around 1.17 basis points per transaction. This supports the idea that outright purchases temporarily increase market liquidity. However, once the Riksbank's holdings reach their average level (approximately 36% of the outstanding amount), the holding effect is associated on average with a decrease of *YI* by 0.15 basis points, which supports the

[37] The low adjusted R-squared indicate that it would be difficult to predict liquidity at weekly frequency using the set of independent variables that we have included in our regression. This is mainly due to the fact that weekly liquidity is noisy, and that some of the independent variables are persistent. This is a similar problem to the one found in the literature about predictive return regressions, where low R-squared are common when one tries to predict one-period returns. In our study however we do not aim at predicting liquidity from our set of independent variables, rather to identify which of these variables plays an important role in affecting market liquidity.

[38] We checked whether the demand effect may have persisted somewhat after the purchases by estimating

$$Liq_{i,t+1} = \alpha_0 + \gamma_i + \delta_t + \alpha_1 Purchases_{i,t} + \varepsilon_{i,t},$$

and find that liquidity in the period (week) after the purchase, i.e. $Liq_{i,t+1}$, was not significantly affected by previous purchases, $Purchases_{i,t}$. We show the results in Appendix IV.

scarcity effect hypothesis that large holdings decrease market liquidity.[39] The *scarcity effect* in this case is five times higher than the demand effect.

Our results also show that the DMO's SLF may have helped to mitigate the *scarcity effect* of the Riksbank's QE program on market liquidity to some extent. The sign of the coefficient is consistently positive across all measures and it is statistically significant for the *Yield Impact* and *VAIV* measures. By providing government bonds to market makers via SLF, the DMO alleviates the shortage of the government bonds in the bond market, which otherwise may be more severe. At the same time, it may be argued that the SLF may create less need for investors to substitute government bonds with riskier assets – which is the way QE is expected to work - and therefore somewhat offset the impact of QE on yields. In addition, the SLF sets a floor for short-term market interest rates (relative to the monetary policy rate) and may counteract the effect of QE on yields to some extent.

Next, we investigate our *nonlinearity* hypothesis. It is reasonable that only when the share of bonds held by the Riksbank grows above a certain threshold bond *scarcity* becomes material and only then affects market liquidity negatively. Identifying a threshold is not a trivial matter. Bond-specific characteristics, issuance volumes, the pace in which the central bank purchases the bonds and general market conditions can all influence the threshold.

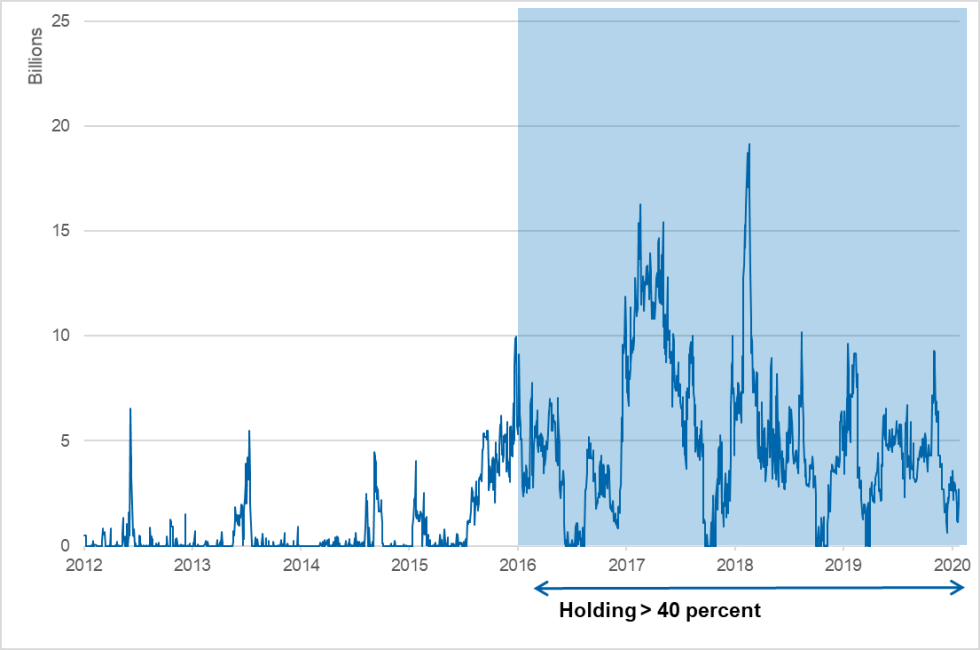
To determine the threshold, we resort to the unique information that the Swedish DMO owns on its SLF volumes on a bond-by-bond basis. In particular, we carefully analyze the usage of the SLF for each bond over the period in our analysis. We find that most of the SLF activity for nominal bonds, both in terms of volume and volatility, increases significantly when the share of the Riksbank's holding becomes larger than (about) 40 percent. As an illustration, Figure 6 shows the data for a representative bond. We interpret such evidence as supportive of the *nonlinearity* of the *scarcity effect*.[40]

We re-estimate our model in equation (1) on the subset of bonds for which the share of the Riksbank's holding is larger (lower) than our threshold, 40 percent. These results are shown in Table 3, panel 2 (higher than 40 percent) and 3 (lower than 40 percent).

[39] The effect of a purchase on transaction costs proxied by yield impact is computed as average purchase size*coefficient of purchases on non-standardized *Yield Impact* = 0.015*2.03. Analogously, the effect of holdings is computed as level of holdings * coefficient of holdings on non-standardized yield impact =0.36*(-0.43). *YI* in the regression is calculated as the change in prices divided by time to maturity (see Appendix II for more details). The calculated effect reflects the average price impact of the purchase and holding adjusted by time to maturity.

[40] Interestingly, this threshold is close to the 33% ECB's limit of bond issuance in its purchase program for government bonds.

Figure 6: The Riksbank's holding and SLF usage



Note: Figure 6 illustrates the usage of the security lending facility (SLF) for one Swedish government bond. The SLF volume is measured in billion SEK The Riksbank's holding of the bond, measured as a percentage of the total outstanding amount of that bond increases to about 40 percent in the beginning of 2016. The shaded area marks the period in which the Riksbank's holdings of that bond are at or above 40 percent.

The results in Table 3 show a significant *nonlinear* impact of bond *scarcity*. For values of holdings lower than 40 percent, we find no impact of the Riksbank QE, neither via *demand* nor *scarcity effect*. More specifically, all the coefficients on *Purchases* - except for the *MEC*- become not significant. Also, the *MEC* has a negative coefficient which means that purchases decrease liquidity. The coefficients on *Holding* are not significant, except the *Turnover Ratio* measure where the coefficient is negative, pointing to a deterioration of *Turnover Ratio* even for holdings lower than 40 percent.

For holdings larger than 40 percent, we find no impact on the two turnover-based measures from *scarcity*, suggesting that the above-40 percent share of the Riksbank does not have a significant negative effect on traded volumes for those bonds. However, the coefficients on all other measures are significant and are also much larger. For example, compared to our baseline results, the increase of the *scarcity effect* on *Yield Impact* – a proxy for transaction costs – is about four times larger when the share of the bonds held by the Riksbank is above 40 percent. This suggests that QE might have a negative impact on trading costs when Riksbank' holdings are large. The *demand effect* becomes stronger as well, as the coefficients on purchases becomes

much larger than in our baseline regression.[41] Intuitively, with much less bonds free to be traded, the impact of *demand* is larger.

Regarding the SLF, we find that the coefficients for all our liquidity measures are not significant when holdings are lower than the 40 percent threshold. For holdings values above the threshold we find that the SLF coefficients remain in line with our baseline regression results in terms of statistical significance but they are larger for the turnover measures, supporting the idea that the facility may have more significantly contributed to liquidity when the Riksbank's holdings are above the threshold. In our robustness checks we analyse thresholds lower and higher than 40 percent.

In Appendix III we report the results for all nominal and inflation-linked bonds. We find a material negative *scarcity effect* of the central bank's holdings and positive *demand* effect for *all* metrics on market liquidity. These results are expected; as inflation-linked bonds are less liquid than nominal bonds, the QE impact on market liquidity is higher when we include them in the sample we analyze.

Overall, the key message from our results is that the deterioration in the level of market liquidity from the *scarcity effect* is significantly larger than the improvement from the *demand effect* and that such effects are *nonlinear*; they tend to be amplified when the share of the Riksbank holdings is larger than a (40 percent) threshold.

6.3 Robustness checks

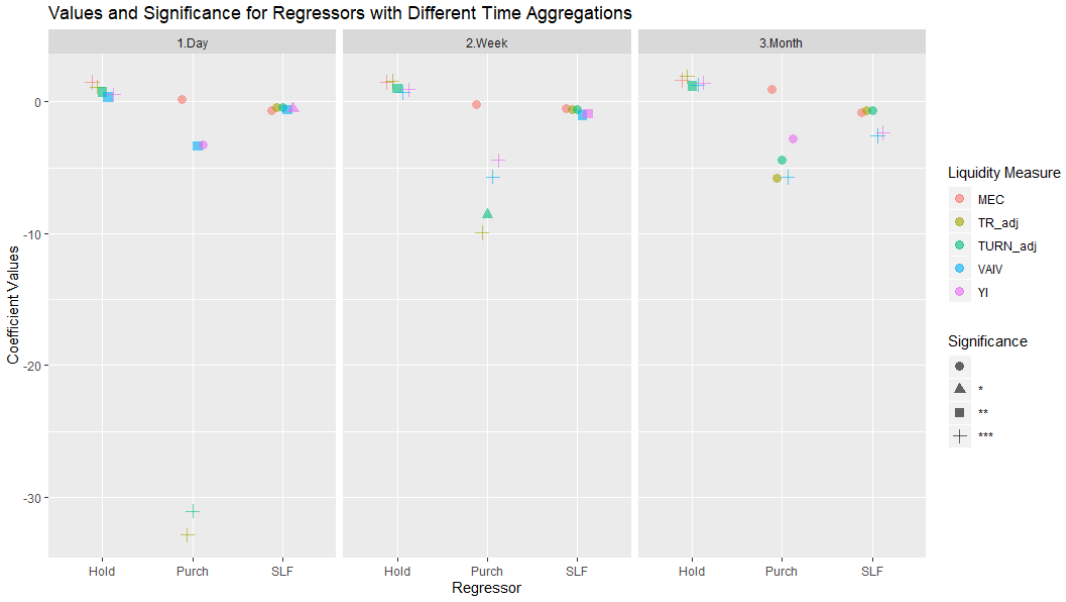
In addition to our baseline model estimation, we consider several robustness exercises. We group them by six different types for convenience. The baseline results are robust to all set of robustness checks as we discuss below.

Time aggregation

We aggregate our variables to weekly frequency to mitigate unduly noise without compromising the quality of the results. Even aggregating the measures to monthly frequency did not change the results in a significant way. In Figure 7 we show graphically our results.[42] Our baseline regression – at weekly frequency - is in the middle panel.

[41] A t-test confirmed that the coefficients in the regression with threshold are statistically different from those in our baseline model.
[42] Tabulate results are available on request.

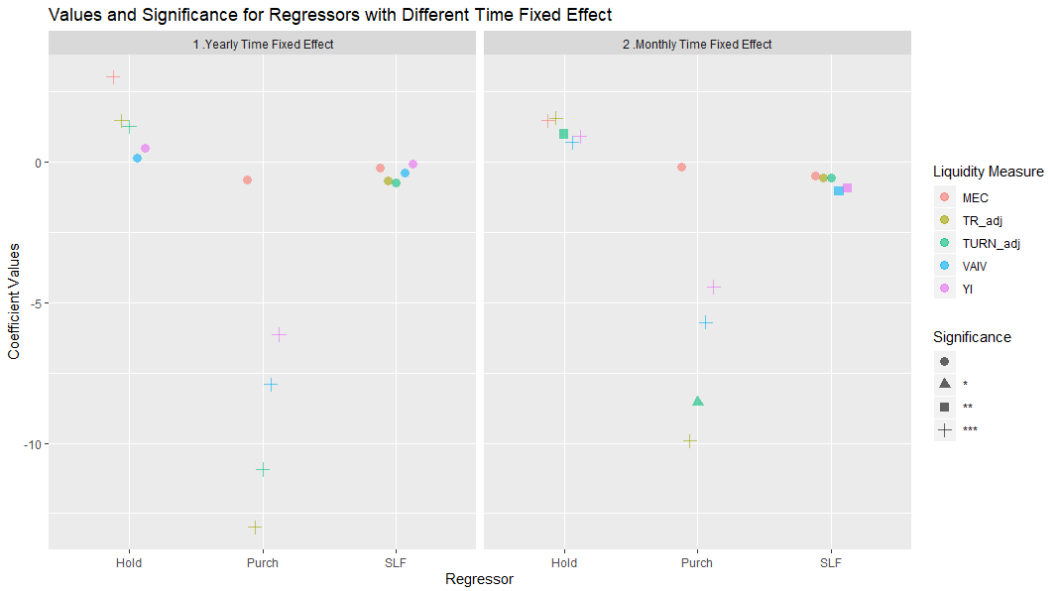
Figure 7. Regression results with different time aggregation



Time fixed-effects

In our baseline specification, we chose to have month time fixed-effect. We checked whether the results would hold to year fixed-effect. Figure 8 shows our results, again graphically. We conclude that the choice of different time fixed-effects does not change our results materially for most of our liquidity measures.

Figure 8. Regression results with different time fixed-effects



Our results are also robust when we do not consider time fixed-effects. Table 4 shows the results. Our controls are measures of macroeconomic stance and variables that relate to the government bond market developments. The set of controls includes the volatility index VIX (in log) as a measure of investors' risk aversion, the business confidence indicator computed by the National Institute of Economic Research, a money market premium as measured by the difference between the tomorrow next interbank (T/N STIBOR) and the monetary policy rate, the spread between the five and two-year government bond yield that takes into account of other factors influencing the government bond market, the debt to GDP ratio and the sovereign bond market liquidity index computed by ESMA. We also include the bond issued volume scaled by the bond total outstanding volume, and the ratio between the volume issued and the public debt. Not surprisingly, both these variables turn to be highly significant and liquidity enhancing.[43]

Taking away the influence of possible outliers

It may be argued that even with time aggregation our measures may be unduly noisy and that outliers may influence and even drive our results at least to some extent. To eliminate the impact of possible outliers, we winsorized our measures at 5 and 95 percent level. We also run the regression with are measures truncated at 5 and 95 percent level. Through winsorization (or truncation), we take away between 10 and 18 percent of total observations depending on the measure. For single bonds, the number of observations may be reduced up to 67 percent. Despite such a reduction in observations, we found that our main results are robust.

Security lending facility, alternative specifications

We find a statistically significant effect of the SLF when we estimate our panel model in equation (1) for two out of five liquidity measures. In particular, we do not find an effect for volume-based measures. At the same time the (one-period lagged) SLF volumes and the share of the Riksbank holdings are relatively high correlated.[44] We therefore orthogonalize the SLF volumes vis-à-vis the *Holding* variable and redo the analysis, but find no material change in our results. We normalize the SLF volumes with the total outstanding (instead of *free float*) and find no material differences.

[43] Our baseline regression include *Issuance* as independent variable.
[44] The correlation coefficient between holdings and SLF is 25%. when we compute the correlation on a bond by bond basis on normalized variables whereas on pooled variables the correlation is 50 percent.

Furthermore, to mitigate the potential endogeneity problem between the SLF variables and our liquidity measures we lagged the SLF variable in our baseline estimation by one period. Considering different lags, up to four periods, i.e. using SLF_{t-2}, SLF_{t-3} or SLF_{t-4} instead of SLF_{t-1} in equation (1) does not change our results.

Table 4. Regression results with control variables and no time-fixed effects

	TURN	***TR***	***VAIV***	***MEC***	***YI***
$Purchases_t$	**12.2*****	**13.06*****	**6.0*****	-0.02	**4.85*****
	(2.42)	(2.34)	(2.05)	(3.57)	(1.49)
$Holding_{t-1}$	**-3.26*****	**-2.72*****	**-0.82****	**-2.32*****	**-1.16****
	(0.43)	(0.48)	(0.39)	(0.74)	(0.46)
SLF_{t-1}	1.59	1.6	0.82	**1.4***	0.54
	(1.13)	(1.13)	(0.77)	(0.84)	(0.66)
$Issuance_t$	**88.47*****	**105.5****	**34.97*****	-0.13	**41.61*****
	(15.72)	(19.7)	(7.68)	(7.77)	(7.55)
$Issuance\text{-}to\text{-}debt_{t-1}$	**36.7*****	**21.38*****	**9.03****	**-9.82***	**11.61*****
	(3.51)	(5.73)	(3.65)	(5.53)	(3.8)
$Debt\ ratio_t$	-1.32	-0.43	**2.87****	-5.45	**3.75****
	(3.18)	(3.05)	(1.43)	(3.75)	(1.87)
$Confidence\ Ind._t$	**-0.02***	**-0.02***	0.01	**0.02****	**0.02****
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
VIX_t	-0.22	-0.2	**-0.51*****	**-0.45*****	**-0.63*****
	(0.17)	(0.17)	(0.14)	(0.13)	(0.17)
$Money\ market\ pr._t$	-0.65	-0.35	0.65	**-2.18*****	**1.13****
	(0.55)	(0.48)	(0.64)	(0.82)	(0.55)
Sov bond liq ind	0.9	0.81	0.02	**1.28*****	-0.33
	(0.55)	(0.61)	(0.27)	(0.43)	(0.3)
$Spread_t$	0.06	0.03	**0.32***	-0.24	0.2
	(0.4)	(0.38)	(0.17)	(0.2)	(0.17)
Adj. R-Squared	0.17	0.15	0.07	0.12	0.12
Number of Obs.	3939	3939	3688	3693	3907

Note: Issuance denotes the bond issued volumes by the DMO scaled by outstanding amount; *Issuance-to-debt* is the ratio between the issued volumes and public debt; *Debt ratio* is the debt to GDP ratio, *Confidence Indicator* is the business confidence indicator published by the National Institute of Economic Research; V*IX* is the log of the VIX; *Money market premium* is the difference between the interbank rate and the monetary policy rate; *Sov bond liq ind* refers to the ESMA sovereign bond market liquidity indicator based on domestic MTS data; *Spread* is the difference between the 5 and 2-year government bond yield. *SLF* is the SLF volumes weighted by the inverse of outstanding amounts. Similarly to baseline regression, *Purchases* and *Holding* are the amount of the bond purchased by the Riksbank scaled by the outstanding amount and the volume of the bond held by the Riksbank scaled by the outstanding amount, respectively. In parenthesis are reported standard errors. *,**,*** denote **p-values** at 10% and 5% and 1% significance, respectively. Data are at weekly frequency.

Regression results with a higher or lower Holdings threshold

In our baseline threshold regression, the threshold is chosen based on the usage of the SLF. In Table 5, we present the results for a lower threshold that we set to 30 percent. As expected, the coefficients are lower in size compared to the baseline threshold results and similar in terms of statistical significance. In particular, for holdings larger than 30 percent of total outstanding, the *Holding* variable has a negative impact on liquidity; for three out of five measures the coefficients are statistically significant. In contrast and similarly to the baseline threshold results, the central bank's purchases have a positive impact on liquidity as measured by the two volume-based measures, i.e. *Turnover* and *Turnover ratio*, and the *VAIV*.

For the sake of completeness, we also perform the regression for a larger value of the threshold, i.e. 50 percent. It is important to note that for values of the threshold above 50 percent there are only few bonds. In addition, the sample size is just 15 percent of the original sample and therefore it is too small to draw strong inferences. Nonetheless, we find most of the results are similar to previous results.

A different source of traded data

Aggregate data on traded volumes for Swedish government bonds is available via SELMA, the Riksbank's reporting of turnover statistics by counterparties for the money and bond markets and foreign exchange market. Notably, SELMA is well known for being a high quality database for aggregate traded volumes. Crosta and Zhang (2020) point out that the volumes observed in MiFID I and MiFID II reporting system do not deviate from the ones reported in SELMA and are therefore as reliable as the SELMA's ones.[45] In addition to their high level of granularity, MiFID I and MiFID II databases are also more extensive than SELMA, since they include all transactions made on Swedish government bonds by any entity under MiFID I and MiFID II, not only the official SELMA reporters.

[45] To have a comparable database, Crosta and Zhang (2020) construct a subsample of MiFID I and MiFID II data that reflects the data collected in SELMA. Among others, in their SELMA-mirroring subsample they only consider the transactions reported by official SELMA reporters, and exclude all transactions between the banks' branches.

Table 5. Regression results with a higher and lower holding's threshold

		TURN	*TR*	*VAIV*	*MEC*	*YI*
Holding>= 30%						
	$Purchases_t$	**35.01*****	**37.81*****	**8.78****	-5.65	5.58
		(6.68)	(6.1)	(3.45)	(7.91)	(4.68)
	$Holding_{t-1}$	-0.61	-0.81	-1.38	**-5.34*****	**-2.57*****
		(1.35)	(1.32)	(0.94)	(0.86)	(0.98)
Holding< 30%						
	$Purchases_t$	2.16	3.22	2.18	-2.3	-0.05
		(4.14)	(2.99)	(2.82)	(2.43)	(2.46)
	$Holding_{t-1}$	0.18	-0.93	**-0.95***	0.02	**-1.1***
		(1.27)	(1.07)	(0.49)	(0.93)	(0.58)
Holding>= 50%						
	$Purchases_t$	**55.35*****	**55.35*****	**13.44****	11.64	9.7
		(11.92)	(12.07)	(6.54)	(7.76)	(10.11)
	$Holding_{t-1}$	**5.07****	**5.06****	**-3.39*****	**-10.09*****	**-5.69*****
		(2.18)	(2.13)	(0.79)	(2.15)	(0.77)
Holding < 50%						
	$Purchases_t$	7.32	**8.93****	4.28	-3.12	2.79
		(5.0)	(3.64)	(3.02)	(2.76)	(2.58)
	$Holding_{t-1}$	**-1.16****	**-1.78*****	-0.39	-0.49	-0.28
		(0.55)	(0.41)	(0.53)	(0.8)	(0.56)
Fixed effect		Yes	Yes	Yes	Yes	Yes
Controls		Yes	Yes	Yes	Yes	Yes
Adj. R-Squared						
Holding >=30%		0.03	0.04	0.07	0.16	0.17
Holding < 30%		0.02	0.03	0.01	0.05	0.02
Holding >=50%		0.06	0.06	0.07	0.18	0.17
Holding < 50%		0.03	0.08	0.02	0.05	0.03
No Obs.						
Holding >=30%		1292	1292	1254	1290	1290
Holding >=50%		575	575	539	574	574

Note: Fixed effects are time (month) and bond fixed effects. *Controls* include the issuance volumes normalized by the bond outstanding amount, the SLF and the ESMA sovereign bond market liquidity index. *, **, *** denote **a significance level at** 90%, 95% and 99%, respectively. Standard errors are reported in parenthesis. Data are aggregated at weekly frequency.

7 Conclusions

QE has become part of the toolbox for monetary policy makers. Yet after a decade of experience with QE policies, the impact of post-crisis central bank asset purchases on market liquidity is not fully understood. Theoretical work has just started to emerge and empirical studies on the effects of QE on liquidity, often limited by the low level of data availability, have been largely inconclusive.

Our paper uses a unique database to study the effect of QE on market liquidity for the Swedish government bond market. To measure liquidity we use a rich and granular dataset based on MiFID transaction data at bond level from 2012 to 2020. This allows us to use information from actual transactions. We compute several measures of liquidity, including transaction price-based measures, and therefore present a more informative picture of market liquidity than in the existing literature, where liquidity measures are mainly based on aggregated – and less informative – data. To our knowledge, our analysis covers the longest time period that has been analysed in this line of research. We are not aware of any other study that employs MiFID transaction data to such extent.

We find that the central bank's purchases of government bonds improved liquidity by increasing the demand of the bonds, i.e. a *demand effect*. Crucially, the Riksbank's holding ratio, the volume purchased in relation to the bond's total outstanding amount, plays a critical role. In particular, after the central bank holding surpasses a cut-off point, market liquidity deteriorates, i.e. a *scarcity effect*. We show that the *scarcity* tends to outweigh the *demand effect nonlinearly*. We use unique information on the usage of the DMO's SLF to determine at which level of central bank's holdings *nonlinearity* materializes.

Importantly, the *nonlinearity* of the impact of QE on market liquidity may explain why the empirical literature has found mixed results.

Our results also indicate that the central bank's QE has an impact on the DMO facilities, which are used to a larger degree by market participants to obtain bonds outside the market after central bank's holding of government bonds increases. We also find that without the facilities, the negative liquidity impact of bond *scarcity* presumably would have been higher.

Importantly, our findings do not necessarily imply that the central bank should not adopt QE policies to pursue its monetary policy goal. However, we show that when the central bank's holdings reach a certain critical level, the QE unduly weakens market liquidity and may even create market dysfunctions, potentially hampering the monetary policy transmission mechanism and the effectiveness of monetary policy.

References

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

BIS (2019a), “Unconventional monetary policy tools: a cross-country analysis”, CGFS Papers 63, Bank for International Settlements, October 2019.

BIS (2019b), “Monetary policy frameworks in EMEs: inflation targeting, the exchange rate and financial stability”, Annual Economic Report 2019.

Blinder, A., Ehrmann, M., de Haan, J. and Jansen, D. J. (2017), “Necessity as the mother of invention: monetary policy after the crisis”, Economic Policy 32 (2017), 707–755

Blommestein, H.J., Elmadag, M.E. and Wellendorph Ejsing, J. (2012), “Buyback and exchange operations: policies, procedures and practices among OECD public debt managers”, OECD Working Papers on Sovereign Borrowing and Public Debt Management 5, OECD Publishing.

Boneva, L., Islami, M. and Schlepper, K. (2021), “Liquidity in the German corporate bond market: has the CSPP made a difference?”, Deutsche Bundesbank Discussion Paper No 9/2021.

Christensen, J. H. E., and Gillan, J.M. (2017), “Does quantitative easing affect market liquidity?”, Working Paper Series 2013-26, Federal Reserve Bank of San Francisco.

Crosta, A., and Zhang, D. (2020), “New liquidity indicators for the fixed-income market”, FI-Analysis nr 21.

D’Amico, S., and King, T.B. (2013), “Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply”, Journal of Financial Economics, Volume 108(2), 425-448.

De Renzis, T., Guagliano, C. and Loiacono, G. (2018), “Liquidity in fixed income markets – risk indicators and EU evidence”, ESMA working paper, 2018.

De Pooter, M., Martin, R., and Pruitt, S. (2018), “The liquidity effects of official bond market intervention”, Journal of Financial and Quantitative Analysis”, 53(1), 243-268.

De Santis, R. (2016),“Impact of the asset purchase programme on euro area government bond yields using market news”, ECB Working Papers Series, no 1939.

Di Casola, P. (2021), “What does research say about the effects of central bank balance sheet policies?”, Economic Commentary No 2 2021, Sveriges Riksbank.

Donier, J., and Bouchaud, J-P. (2015), “Why do markets crash? Bitcoin data offers unprecedented insights”, PLoS ONE, 10.

Ferdinandusse, M., Freier, M. and Ristiniemi, A. (2020), “Quantitative easing and the price-liquidity trade-off”, ECB working paper series No. 2399.

Fleming, M. J. and Ruela, F. (2020), “Treasury market liquidity during the COVID-19 crisis”, Liberty Street Economics 20200417, Federal Reserve Bank of New York.

Gagnon, J, Raskin, M., Remache ,J. and Sack, B. (2011), “The financial market effects of the Federal Reserve's large-scale asset purchases”, International Journal of Central Banking, vol 7, no 1, March, pp 3–43.

Han, F., and Seneviratne, D. (2018), “Scarcity effects of quantitative easing on market liquidity: evidence from the Japanese government bond market”, IMF working paper Nr 18/96.

Hasbrouck, J. and Schwartz, R. A. (1988), “Liquidity and execution costs in equity markets”, Journal of Portfolio Management Spring 1988, 14, 10-16.

International Monetary Fund (2015), “Market liquidity – resilient or fleeting?”, IMF Global Financial Stability Report, ch. 2, 49-82.

Joyce, M., Lasaosa, A., Stevens, I. and Tong M., 2011. "The Financial Market Impact of Quantitative Easing in the United Kingdom", International Journal of Central Banking, vol. 7(3), 113-161.

Kandrac, J. (2018), “The costs of quantitative easing: liquidity and market functioning effects of Federal Reserve MBS purchases”, International Journal of Central Banking, 56.

Kandrac, J. and Schlusche, B. (2013), “Flow effects of large-scale asset purchases”, Economics Letters, Vol. 121, 330-335.

Krishnamurthy, A. and Vissing-Jorgensen, A. (2011), “The effects of quantitative easing on interest rates: channels and implications for monetary policy”, Brookings Papers on Economic Activity, no 2, pp 215–65.

Pelizzon, L., Subrahmanyam M. G., Tobe R. and Uno J. (2018), "Scarcity and spotlight effects on liquidity: quantitative easing in Japan", https://ssrn.com/abstract=3107603 or http://dx.doi.org/10.2139/ssrn.3107603 .

Sarr, A. and Lybek, T. (2002), "Measuring liquidity in financial markets", IMF Working Paper Nr 02/232.

Schlepper, K., Hofer, H., Riordan, H. and Schrimpf, A. (2017), "Scarcity effects of QE: a transaction-level analysis in the Bund market", Bundesbank Discussion Paper No. 06/2017.

SNDO (2017), Central Government Borrowing Report No 3, 2017.

Swedish Financial Supervisory Authority (2019), "New rules led to reduced transparency on the Swedish bond markets", FI Supervision No 15, 2019.

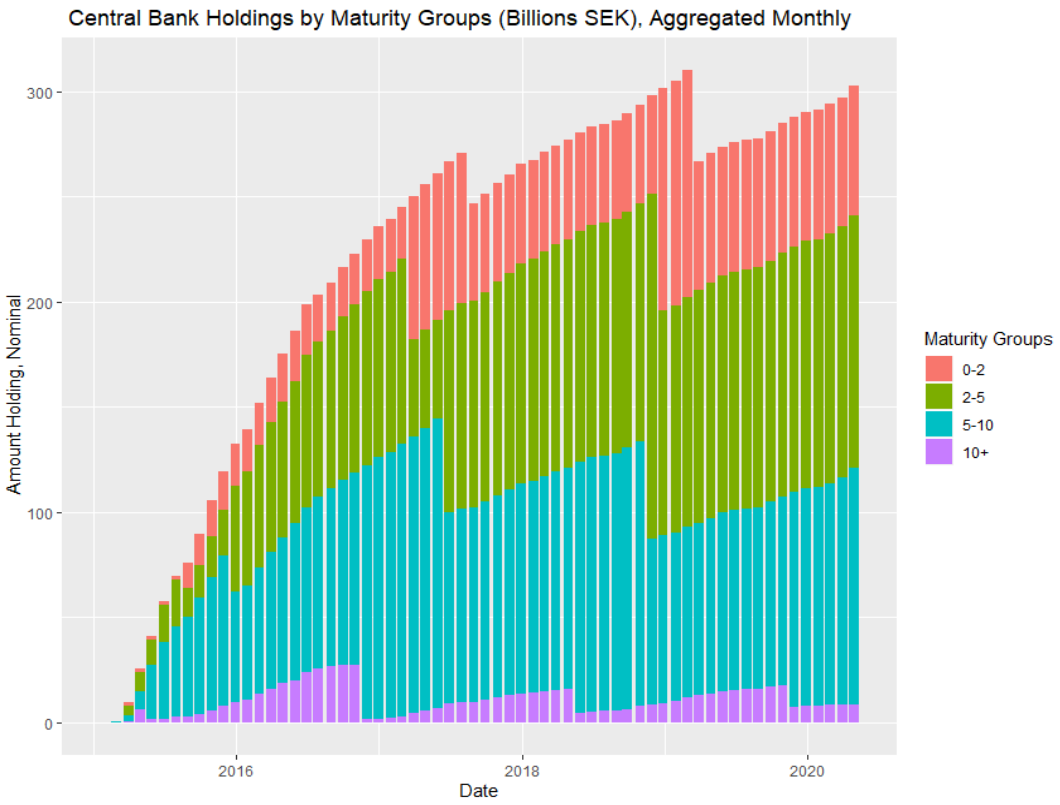
Williamson, S. (2006), "Scarce collateral, the term premium, and quantitative easing", Journal of Economic Theory, Vol. 164, 136-165.

World Bank Group (2015), "Securities lending and related standing facilities: background note", World Bank, Washington, DC.

APPENDIX I

Figure AI.1. Riksbank purchases of nominal government bonds, by maturity

Figure AI.2. Riksbank purchases of nominal government bonds, billion SEK



APPENDIX II

Data Filtering

In order to remove potential errors in the reported data and primary market transactions, we apply similar filtering rules as in Crosta and Zhang (2020). We apply these rules whenever necessary for the specific liquidity measure, which means that, for instance, price filtering is only applied when computing price-based measures. We choose to do so in order to keep all useful information available in each transaction report. A non-exhaustive list of filtering rules is described below: [46]

a. Bond prices are allowed to vary between 80 and 250 SEK. These boundaries ensure that we remove all transactions where a price was most likely reported in percentage points. Moreover, any breach of these limits would result in implausible yields for our sample of bonds.
b. The calculated trade-by-trade return (intraday) can only vary between -1% and 1%. This allows us to depict transactions where reported prices are very different from the general price level at that time.
c. Data on primary market transactions are reported on a non-regular basis. As we are only interested in secondary market transactions, we remove all transactions where the Swedish National Debt Office was reported as a counterparty in a transaction.
d. In order to remove wrongly reported trade volumes, we allow trading volume for a single transaction only to be smaller than 50% of the total outstanding amount. Moreover, we remove the top and bottom percentile of the transactions based on their traded volume. We do so to ensure that our results are not driven by retail transactions, nor by volumes reported in percentage points instead of SEK.
e. Both parties in a transaction must report their trades. Therefore, these transactions will be reported twice. We implement a filtering routine to depict these double-reported trades and remove one of them. As mentioned before in the robustness check section, we doublecheck that our aggregate volumes are consistent with the volumes reported in SELMA database.

The raw data consist of 802,102 reported transactions, of which 640,739 are for nominal bonds and 161,363 are for inflation-linked bonds. Our final sample amounts to 316,413 unique transactions, of which 260,948 on nominal bonds and 55,465 on inflation-linked bonds.

[46] Other columns, i.e., transaction data and time as well as buyer and seller identifications, are also used in order to filter out duplicate transactions in the data. Duplicate transactions in terms of trading date and time (specified in second), instrument ISIN, buyer ID, seller ID, transaction price and volume are also removed from the sample.

Liquidity dimensions and measures

A market where liquidity is high, it is often characterized by low transaction costs and by the possibility of quickly executing large transactions with low price impact. These characteristics of a liquid market can be used to describe market liquidity, so that each characteristic corresponds to a different dimension of liquidity. The academic literature suggests five distinct dimensions: tightness, immediacy, depth, breadth, and resilience (see Sarr and Lybek, 2002).

In order to capture as much as possible each of these liquidity dimensions we use the same approach described in Crosta and Zhang (2020). In particular, we employ five of their liquidity indicators that are best suited for the government bond market. Each measure is computed at bond level. In our regression analysis, we take the weekly average of each measure computed at daily frequency.

a) Total trading volume per day (TURN)

TURN is calculated as the average of the total trading volume per day for bond *i* as follows:

$$\text{TURN}_{i,t} = \sum_{i}^{N} \text{traded volume}_{i,j,t},$$

where $\text{traded volume}_{i,j,t}$ is the traded volume on transaction *j* on day *t* for bond *i*. High TURN values indicate high liquidity.

b) Turnover ratio (TR)

TR is described among others by Sarr and Lybek (2002) and is calculated per day *t* as the total daily turnover in relation to the outstanding volume for bond *i*. The measure shows, in other words, the share of the issued amount that is traded during day *t*:

$$\text{TR}_{i,t} = \frac{\text{TURN}_{i,t}}{\text{Total outstanding}_{i,t}}.$$

The higher the TR, the larger share of the bond is traded per day, which means that market liquidity is also higher.

c) Yield impact (YI)

We use a modified version of the Price Impact (PI) liquidity indicator (Amihud 2002) for the stock market, where returns are adjusted by the remaining time to maturity for the bond instead of the transaction volume. We do this for two reasons. First, unlike in the stock market, there is no indication that larger transactions have a greater impact on price on bilateral trades in bonds. We observe instead a weak and negative relationship between volumes and the impact on price. Second, we need to consider that bond prices in Sweden, by convention, are reported in basis points and not in absolute SEK. These basis points, which are usually called yield to maturity, correspond to the annual return the investor can expect from holding onto the bond until it matures.

The duration describes how sensitive the price is to changes in the annual expected return. In general, the duration for long bonds is higher than for short bonds. Higher duration means a higher change in price as a result of a change in interest rates. We use time to maturity to adjust the returns since duration data is not directly available, and we define the daily YI indicator per bond *i* and day *t* as follows:

$$\mathrm{YI}_{i,t} = \frac{\mathrm{PI}_{i,t}}{(\text{time to maturity in yr})_{i,t}},$$

and

$$\mathrm{PI}_{i,t} = \frac{1}{N}\sum_{k}^{\mathrm{N}} \frac{\left|\mathrm{p}_{i,t,k} - \mathrm{p}_{i,t,k-1}\right|}{\mathrm{p}_{i,t,k-1}},$$

where $p_{i,t,k}$ is the price of transaction *k* during day *t* for bond *i*. YI measures the transaction costs by describing how many basis points are needed to buy and then immediately sell a bond. The measure therefore captures the dimension tightness. The higher YI, the lower market liquidity is presumed to be.

d) Market Efficiency Measure (MEC)

MEC was described first in Hasbrouck and Schwartz (1988) and is based on the assumption that price volatility is more or less constant in liquid markets, even when the prices is constantly – but temporarily – influenced by new information. The variance of daily prices changes therefore should not differ significantly from the variance of price changes over longer horizons. In other words, short and long term volatility tend to converge when markets are

resilient. We build our indicators as the absolute difference between Hasbrouck and Schwartz's MEC indicator and 1, so that high values of MEC mean that the value of our indicator is low:

$$\mathrm{MEC}_{i,t} = \sum_{i}^{\mathrm{N}} \left| \frac{Var\ (\mathrm{R}_{i,t})}{T * Var\ (\mathrm{r}_{i,t})} - 1 \right|$$

where $Var\ (R_{i,t})$ and $Var\ (r_{i,t})$ are the variance of returns over a five-day period and variance of returns over a one-day period for bond *i*, and T is the number of short periods in each longer time period (which means that in our case T = 5). MEC measures how resilient a market is for sudden shocks. A higher MEC means lower liquidity, all else being equal.

e) Volume-Adjusted Intraday Volatility (VAIV)

VAIV is a modified version of the indicator described in Donier and Bouchaud (2015). Their indicator is based on the order book data, where trade is continuous. Liquidity can then be described as a reaction to imbalances in the order flows. We adapt Donier and Bouchaud's indicator for the bond market, so that our indicator is calculated as a ratio between the intraday volatility during a day and the total daily turnover. We define our liquidity indicator VAIV as

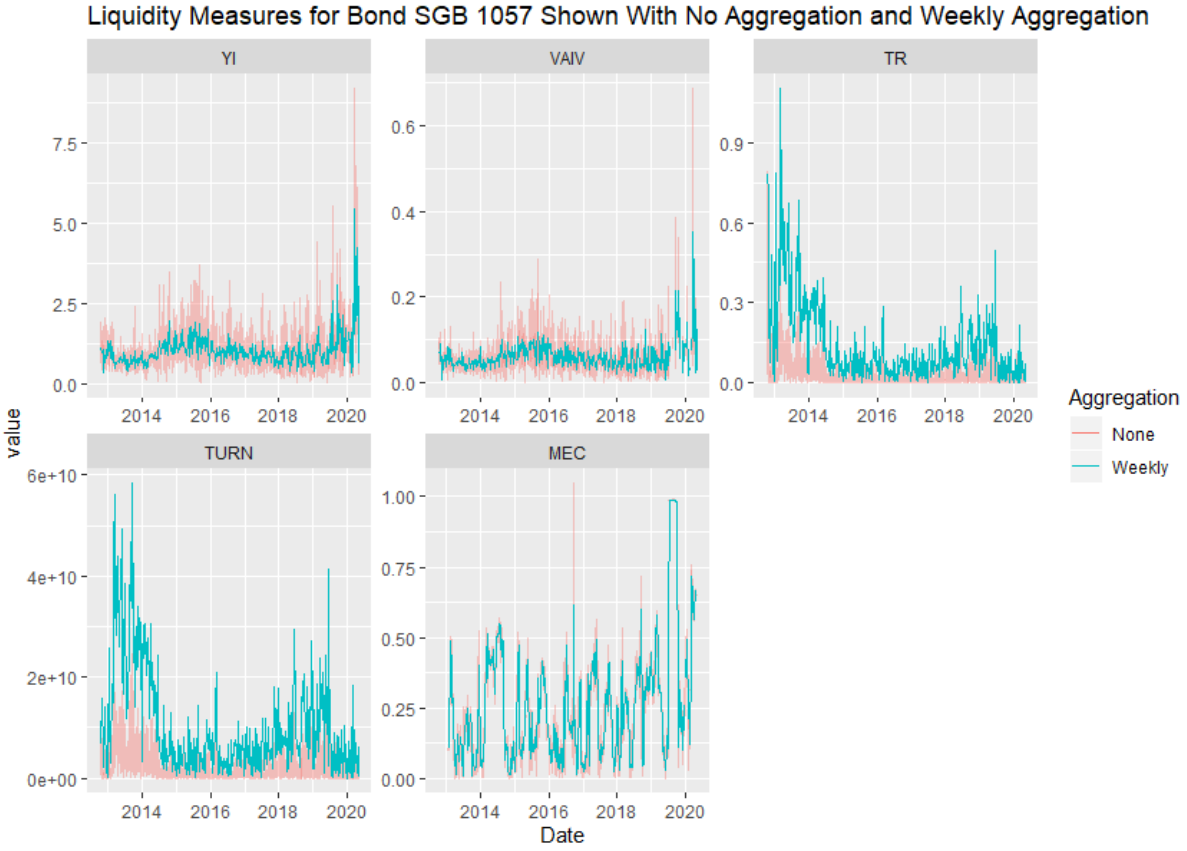
$$VAIV_{i,t} = \frac{1}{N} \sum_{i}^{\mathrm{N}} \frac{\sigma(r_{i,t})}{\ln(\mathrm{TURN}_{i,t})},$$

where $\sigma(r_{i,t})$ is the volatility of returns on bond *i* during day *t* and $\ln(\mathrm{TURN}_{i,t})$ is the natural logarithm of the total turnover of the same bond *i* during the same day *t*. We use return adjusted by the time to maturity to be able to have comparable measure of volatility between bonds with different maturities since bonds with lower maturity usually show higher price sensitivity and therefore higher price volatility. One advantage of VAIV is that it considers situations where volatility is low due to limited trade activity (which indicates low liquidity) as well as situations where the turnover is high but prices fluctuate significantly due to market frictions (which also is a sign of low liquidity). High VAIV values indicate that liquidity is low.

Table AII. Summary statistics (daily frequency)

Indicator	Name	No. Obs	Mean	St.Dev.
Turnover (in mSEK)	TURN	30 223	1 407.3	2 943.9
Nominal		*18 498*	*2 110.9*	*3 538.2*
Inflation-linked		*11 725*	*297.3*	*758.6*
Turnover ratio (in %)	TR	30 223	2.51	5.3
Nominal		*18 498*	*3.33*	*6.0*
Inflation-linked		*11 725*	*1.22*	*3.6*
Yield impact (in bps)	YI	25 286	1.27	1.33
Nominal		*17 195*	*1.17*	*1.25*
Inflation-linked		*8 091*	*1.49*	*1.47*
Market Efficiency Measure	MEC	23 900	0.44	0.33
Nominal		*16 465*	*0.29*	*0.21*
Inflation-linked		*7 435*	*0.79*	*0.28*
Volume-Adjusted Intraday Volatility	VAIV	17 252	0.07	0.07
Nominal		*13 646*	*0.07*	*0.06*
Inflation-linked		*3 606*	*0.08*	*0.07*

Figure AII. Liquidity measures for a representative bond, daily and weekly frequency



APPENDIX III

Table AIII: Regression results for nominal and inflation-linked bonds

	TURN	TR	VAIV	MEC	YI
$Purchases_t$	**8.01****	**9.54*****	**6.56*****	3.11	**6.48*****
	(3.62)	(3.0)	(1.69)	(3.8)	(1.39)
$Holding_{t-1}$	**-1.08*****	**-1.67*****	**-0.78*****	**-1.78*****	**-1.05*****
	(0.34)	(0.27)	(0.25)	(0.53)	(0.24)
Fixed effect	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
R-Squared	0.03	0.07	0.03	0.06	0.05
No. of Obs.	6817	6817	5556	6195	6601

Note: Fixed effects are time (month) and bond fixed effects. *Controls* include the issuance volumes normalized by the bond outstanding amount and the ESMA sovereign bond market liquidity index. *, **, *** denote **a significance level at** 90%, 95% and 99%, respectively. Standard errors are reported in parenthesis. Data are aggregated at weekly frequency.

APPENDIX IV

We checked for potential endogeneity that may arise in the case the Riksbank systematically bought bonds that were more liquid, by estimating the following regression:

$$Purchases_{i,t} = \alpha_0 + \gamma_i + \delta_t + \alpha_1 Liq_{i,t-1} + \varepsilon_{i,t}.$$

Table AIV.1 here below shows the results.

Table AIV.1: Regression results for endogeneity of Riksbank's purchases

	Purchases	*Purchases (Holding>40 percent)*	*Purchases (Holding<40 percent)*
TR_{t-1}	-0.01	**1.22*****	-0.23
	(0.33)	(0.29)	(0.24)
MEC_{t-1}	0.02	**0.36***	-0.16
	(0.07)	(0.2)	(0.11)
$VAIV_{t-1}$	0.24	0.17	0.15
	(0.3)	(0.43)	(0.78)
YI_{t-1}	0.04	0.1	0.00
	(0.03)	(0.06)	(0.04)
Fixed effect	Yes	Yes	Yes
Controls	No	No	No
R-Squared	0.00	0.01	0.00
No. of Obs.	2922	765	2157

Note: Fixed effects are time (month) and bond fixed effects. *, **, *** denote **a significance level at** 90%, 95% and 99% respectively. Standard errors are reported in parenthesis. Data are aggregated at weekly frequency.

We also checked whether the *demand effect* may have persisted after the Riksbank's purchases by estimating the following regression:

$$Liq_{i,t+1} = \alpha_0 + \gamma_i + \delta_t + \alpha_1 Purchases_{i,t} + \varepsilon_{i,t}.$$

Table AIV.2 here below shows the results.

Table AIV.2: Regression results for persistence of demand effect

	TURN	**TR**	**VAIV**	**MEC**	**YI**
$Purchases_t$	2.21	5.68	**6.62****	-0.13	3.94
	(6.12)	(7.09)	(2.73)	(2.39)	(3.48)
Fixed effect	Yes	Yes	Yes	Yes	Yes
Controls	No	No	No	No	No
R-Squared	0.02	0.02	0.00	0.02	0.01
No. of Obs.	3172	3172	2949	2949	3142

Note: Fixed effects are time (month) and bond fixed effects. *, **, *** denote **a significance level at** 90%, 95% and 99% respectively. Standard errors are reported in parenthesis. Data are aggregated at weekly frequency.

Recent Working Papers:

For a complete list of Working Papers published by Sveriges Riksbank, see www.riksbank.se

The Macroeconomic Effects of Trade Tariffs: Revisiting the Lerner Symmetry Result *by Jesper Lindé and Andrea Pescatori*	2019:363
Biased Forecasts to Affect Voting Decisions? The Brexit Case *by Davide Cipullo and André Reslow*	2019:364
The Interaction Between Fiscal and Monetary Policies: Evidence from Sweden *by Sebastian Ankargren and Hovick Shahnazarian*	2019:365
Designing a Simple Loss Function for Central Banks: Does a Dual Mandate Make Sense? *by Davide Debortoli, Jinill Kim and Jesper Lindé*	2019:366
Gains from Wage Flexibility and the Zero Lower Bound *by Roberto M. Billi and Jordi Galí*	2019:367
Fixed Wage Contracts and Monetary Non-Neutrality *by Maria Björklund, Mikael Carlsson and Oskar Nordström Skans*	2019:368
The Consequences of Uncertainty: Climate Sensitivity and Economic Sensitivity to the Climate *by John Hassler, Per Krusell and Conny Olovsson*	2019:369
Does Inflation Targeting Reduce the Dispersion of Price Setters' Inflation Expectations? *by Charlotte Paulie*	2019:370
Subsampling Sequential Monte Carlo for Static Bayesian Models *by David Gunawan, Khue-Dung Dang, Matias Quiroz, Robert Kohn and Minh-Ngoc Tran*	2019:371
Hamiltonian Monte Carlo with Energy Conserving Subsampling *by Khue-Dung Dang, Matias Quiroz, Robert Kohn, Minh-Ngoc Tran and Mattias Villani*	2019:372
Institutional Investors and Corporate Investment *by Cristina Cella*	2019:373
The Impact of Local Taxes and Public Services on Property Values *by Anna Grodecka and Isaiah Hull*	2019:374
Directed technical change as a response to natural-resource scarcity *by John Hassler, Per Krusell and Conny Olovsson*	2019:375
A Tale of Two Countries: Cash Demand in Canada and Sweden *by Walter Engert, Ben Fung and Björn Segendorf*	2019:376
Tax and spending shocks in the open economy: are the deficits twins? *by Mathias Klein and Ludger Linnemann*	2019:377
Mind the gap! Stylized dynamic facts and structural models *by Fabio Canova and Filippo Ferroni*	2019:378
Financial Buffers, Unemployment Duration and Replacement Labor Income *by Mats Levander*	2019:379
Inefficient Use of Competitors' Forecasts? *by André Reslow*	2019:380
How Much Information Do Monetary Policy Committees Disclose? Evidence from the FOMC's Minutes and Transcripts *by Mikael Apel, Marianna Blix Grimaldi and Isaiah Hull*	2019:381
Risk endogeneity at the lender/investor-of-last-resort *by Diego Caballero, André Lucas, Bernd Schwaab and Xin Zhang*	2019:382
Heterogeneity in Households' Expectations of Housing Prices – Evidence from Micro Data *by Erik Hjalmarsson and Pär Österholm*	2019:383
Big Broad Banks: How Does Cross-Selling A Affect Lending? *by Yingjie Qi*	2020:384
Unemployment Fluctuations and Nominal GDP Targeting *by Roberto Billi*	2020:385
FAQ: How do I extract the output gap? *by Fabio Canova*	2020:386

Drivers of consumer prices and exchange rates in small open economies *by Vesna Corbo and Paola Di Casola*	2020:387
TFP news, stock market booms and the business cycle: Revisiting the evidence with VEC models *by Paola Di Casola and Spyridon Sichlimiris*	2020:388
The costs of macroprudential deleveraging in a liquidity trap *by Jiaqian Chen, Daria Finocchiaro, Jesper Lindé and Karl Walentin*	2020:389
The Role of Money in Monetary Policy at the Lower Bound *by Roberto M. Billi, Ulf Söderström and Carl E. Walsh*	2020:390
MAJA: A two-region DSGE model for Sweden and its main trading partners *by Vesna Corbo and Ingvar Strid*	2020:391
The interaction between macroprudential and monetary policies: The cases of Norway and Sweden *by Jin Cao, Valeriya Dinger, Anna Grodecka-Messi, Ragnar Juelsrud and Xin Zhang*	2020:392
Withering Cash: Is Sweden ahead of the curve or just special? *by Hanna Armelius, Carl Andreas Claussen and André Reslow*	2020:393
Labor shortages and wage growth *by Erik Frohm*	2020:394
Macro Uncertainty and Unemployment Risk *by Joonseok Oh and Anna Rogantini Picco*	2020:395
Monetary Policy Surprises, Central Bank Information Shocks, and Economic Activity in a Small Open Economy *by Stefan Laséen*	2020:396
Econometric issues with Laubach and Williams' estimates of the natural rate of interest *by Daniel Buncic*	2020:397
Quantum Technology for Economists *by Isaiah Hull, Or Sattath, Eleni Diamanti and Göran Wendin*	2020:398
Modeling extreme events: time-varying extreme tail shape *by Bernd Schwaab, Xin Zhang and André Lucas*	2020:399
The Effects of Government Spending in the Eurozone *by Ricardo Duque Gabriel, Mathias Klein and Ana Sofia Pessoa*	2020:400
Narrative Fragmentation and the Business Cycle *by Christoph Bertsch, Isaiah Hull and Xin Zhang*	2021:401

Sveriges Riksbank
Visiting address: Brunkebergs torg 11
Mail address: se-103 37 Stockholm

Website: www.riksbank.se
Telephone: +46 8 787 00 00, Fax: +46 8 21 05 31
E-mail: registratorn@riksbank.se