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The scarcity effect of QE on repo rates: Evidence from the euro area☆

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ABSTRACT

Most short-term interest rates in the euro area are below the European Central Bank deposit facility rate, the rate at which the central bank remunerates banks for excess reserves. This coincided with the start of the Public Sector Purchase Program (PSPP) launched in March 2015. In this paper, we explore empirically the interactions between the PSPP and repo rates. Using proprietary data from PSPP purchases and repo transactions for specific ("special") securities, we assess the scarcity channel of PSPP and its impact on repo rates. We estimate that purchasing 1% of a bond outstanding is associated with a decline of its repo rate of 0.78 basis points.

1. Introduction

The market for repurchase agreements ("repo") allows financial market participants to borrow and lend cash against collateral. It is by far the largest segment of the euro area money market, with a quarterly turnover of 28,000 billion euros -more than ten times the amount traded on the unsecured money market[1]. As such, it plays a critical role in the transmission of monetary policy.

Repo rates have gained substantial attention in recent years after they began moving out of sync with the European Central Bank policy rates (see, for instance, "Why is the European repo market under pressure?").[2] Following the start of the Public Sector Purchase Programme (PSPP) in March 2015–the European version of quantitative easing[3]–repo rates not only dropped in negative territory

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[1] ECB (2015d)

[2] Financial Times (2016): https://www.ft.com/content/7b413b0c-960f-11e6-a80e-bcd69f323a8b

[3] The ECB PSPP started in March 2015 as part of the the ECB asset purchases program. The program focuses on bonds issued by euro area gov-

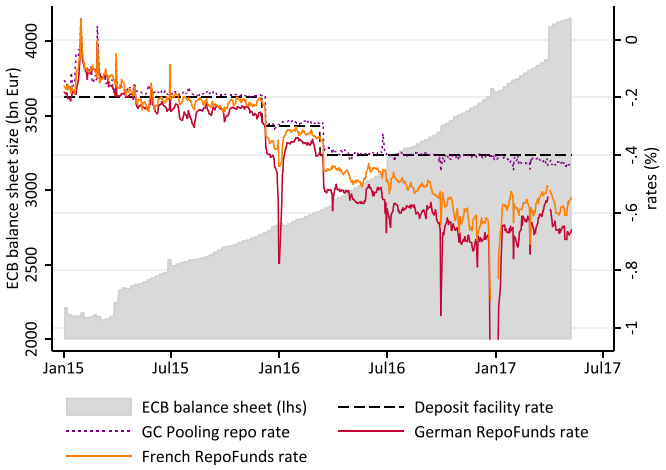


Fig. 1. Selected money market rates in the euro area. *Note:* Data are from Bloomberg, RepoFunds Rate. RepoFunds rates are not shown between December 23, 2016 and January 4, 2017 and not on March 31, 2017. RepoFunds rates are computed from volume-weighted transactions on Brokertec and MTS platforms and by large composed of special repo rates. We interpret them as such, as opposed to a general collateral rates, which GC pooling is an example of. See http://www.eurexrepo.com/repo-en/products/gcpooling.

but declined markedly below the ECB deposit facility rate (DFR), currently set at -40 basis points (bps). This can be seen on Fig. 1.

This is all the more surprising given the fact that at this rate, the European Central Bank (ECB) remunerates the excess reserves of all banks without any limit, in principle preventing transactions on the money market to be concluded at a lower interest rate. Explaining the evolution of repo rates, why they were able to decline below the DFR, and how this development could be linked to the Eurosystem's bond purchases is the main subject of this paper. Answers to these questions have important implications for monetary policy implementation.

We first consider the impact of the excess liquidity, inherent to any central bank liquidity providing operations on the level of repo rates. Excess liquidity is the liability counterpart of asset purchases. It may be the case that the large amount of central bank reserves created as a byproduct of asset purchases pushed repo rates below the DFR. This would be reminiscent of the US experience, where money market rates have been below the rate of interest on excess reserves (IOER) since 2008 (see Bech and Klee, 2011).

This mechanism relies on market segmentation and crucially on the fact that banks with access to the central bank's remuneration of reserves acquire some bargaining power on the money market and remunerate nonbanks (which do not receive interest on their reserves) at a lower rate. This seems consistent with recent findings on the Eurosystem PSPP (Koijen et al., 2017) showing the final counterparties of asset purchases were mostly counterparties with no direct access to the DFR in the euro area. According to this hypothesis, the larger the amount of central bank liquidity in the system, the larger should be the gap between money market rates and the DFR. This mechanism is described in more detail in Section 2.1, and some anecdotal evidence are presented to support its empirical relevance.

The bulk of this paper and its main contribution focus, however, on a different mechanism: the fact that asset purchase have an effect on individual bond scarcity. We devote most of the empirical analysis to this effect. By purchasing bonds, the Eurosystem decreases the net supply available in the market and makes these bonds, all things equal, scarcer. Some financial intermediaries may need these bonds for different purposes (for instance, to deliver them after a short sale or for regulatory reasons) that we detail in Section 2. Since their main motivation to enter in a repo transaction is to borrow this bond against cash, they might be ready to lend their cash at a lower rate. This phenomenon is known as specialness (Duffie, 1996). In the presence of specialness, repo rates can decline below the DFR.

We recover two years of repo transactions data from Brokertec, the largest electronic repo platform for European governements bonds. We focus on bonds issued by the seven largest euro area countries, at daily frequency between January 2, 2015 and May 9, 2017. We investigate at the security level the determinants of repo rates and whether they are affected by the purchases made by the Eurosystem. For this purpose, we combine data from Brokertec with proprietary data on purchases of euro area government bonds made under the PSPP program.

Using panel regressions with bond and country-maturity-time fixed effects, our results support the explanation, according to which the scarcity of individual bonds affects their specific repo rates: on average, we find that 1% of a bond outstanding purchased is associated with a decline of about 0.78 bps in its repo rate. We also find that excess liquidity has its own contribution through more aggregated effects.

As the decision by the central bank to purchase a given bond might be influenced by its relative repo rate, we

ernments, public entities, and supra-national institutions. It is the largest bond buying program in the history of the Eurosystem and is colloquially known as quantitative easing.

propose an instrumental variable approach to deal with possible endogeneity issues. We make use of predetermined rules set by the Eurosystem before the start of the program regarding the maturity and the timing of the purchases. These rules are completely unrelated to the repo market and can explain a sufficient part of the variations in bond purchases. A Two-Stage Least Squares (2SLS) regression shows that, once properly estimated, the effect is found to be six times larger than when using Ordinary least squares (OLS). To our knowledge, our paper is the first to estimate the effect of asset purchases on specialness, free of this bias.

Our findings have potentially important implications for monetary policy. First, it might be challenging for the central bank to pass on one-for-one future policy rate changes in a context of increased dispersion of money market rates. For instance, ECB executive board member Benoît Coeuré declared:"there is a risk that, under the current framework, some short-term market rates would not respond fully to changes in our key interest rates or, even if they would, that a continued dispersion of short-term rates would adversely impact the transmission of our monetary policy stance".[4] In a sense, central banks asset purchases–aiming at flattening the yield curve–might result in partially losing control over the short end of the curve (i.e., money market rates). This trade-off between controlling the short end and the long end of the yield curve is likely to play a significant role in the conduct of monetary policy going forward.

To deal with these issues, central banks have several instruments at their disposal. Some are related to the management of excess liquidity when the floor set by the central bank becomes "leaky," including the perimeter of institutions having access to the central bank's facilities. If individual bonds scarcity is the main driver of repo rates deviations, a securities lending facility may alleviate these pressures. Under such a facility, the central bank may lend out the bonds it has purchased.

One additional important policy implication can be drawn from our paper. The existing literature has shown that lower repo rates imply lower yields for the underlying security (Jordan and Jordan, 1997). This means that the effect of asset purchase programs on bond yields could be explained by the abnormally low repo rates that these purchases trigger. In other words, specialness is one of the channels through which central bank asset purchases programs can lower bond yields.[5]

Our paper is related to three strands of literature. First, we contribute to the empirical literature on bond specialness, which includes, for instance, Jordan and Jordan (1997), Buraschi and Menini (2002), or Krishnamurthy (2002). More specifically, we study the role of central bank purchases on the specialness premium, like (D'Amico et al., 2018), who have conducted a similar exercise in the case of the Federal Reserve's quantitative easing, and Corradin and Maddaloni (2017), who have explored the impact of Eurosystem's interventions in 2011 on the Italian repo market. The results of these two studies are consistent with ours. Ferrari et al. (2016) also look at the increase in the specialness premium in the euro area but do not use bond-by-bond data for the central bank asset purchases.

Second, we make extensive use of the theoretical literature on specialness and in particular of the seminal work of Duffie (1996). Other theoretical contributions include, for instance, Fisher (2002), Bottazzi et al. (2012), and more recently, Huh and Infante (2017) and Duffie and Krishnamurthy (2016). As explained in Section 2, our results confirm all the intuitions from this literature.

Third, we also rely on the literature dealing with central bank interventions and money market rates. We use the results derived in the context of the post-2008 US federal funds markets to explain part of the decline of money market rates below the DFR. Contributions to this literature include for instance Bech and Klee (2011), Martin et al. (2015), Garratt et al. (2015), or Armenter and Lester (2017), as detailed in Section 2.

The remainder of the paper is organized as follows. Section 2 elaborates on the different mechanisms linking asset purchases and the repo rates. Section 3 describes the data, and Section 4 outlines our empirical strategy. We then provide our results in Section 5 and discuss the policy implications in Section 6. Section 7 concludes.

2. The repo market and central bank asset purchases: an interplay of different possible mechanisms

The market for repurchase agreements (repo) allows participants to borrow and lend cash against collateral (i.e., a security and generally a bond). For this reason, this market is said to provide secured funding, as opposed to the unsecured funding market. A repo transaction involves two counterparties: counterparty A lends one euro of cash against a bond i (the collateral) at time t, at an interest rate r to counterparty B. At $t+1$, the trade is reversed. A gets $1+r$ euro of cash, and B recovers its bond. A haircut is generally applied to the collateral; that is, one can borrow 95 in cash against 100 of collateral (in this case the haircut is 5%).

Some repo transactions are secured by securities from a basket of collateral. Bonds belonging to this basket–and by extension repo transactions made against it–are said to be general collateral (GC). In those transactions, the collateral that will be delivered is not known when the trade is negotiated, but the bond is listed in the prespecified GC basket. The main motivation to enter into a GC repo transaction is a priori to lend/borrow cash (Mancini et al., 2016; D'Amico et al., 2018). This rate is usually seen as a risk-free money market rate in the literature.

Other repo transactions involve a specific security as collateral. When the repo is initiated, it is specified which security (which isin code) has to be delivered against the cash: this market is said to be the special–or specific–collateral repo market (SC). Section 2.3 elaborates on the motives to enter this market and to lend/borrow a specific bond rather than GC. Borrowing a specific bond on the repo market (and thus lend cash) may come at a cost and requires paying a premium for it in the form of a lower remuneration of cash. If, for example, the GC rate is at

[4] Reuters (2018).

[5] This is also the conclusion reached by the Swedish authorities, which have had a similar dynamic on their repo market during their assets purchase program (Flodén, 2018).

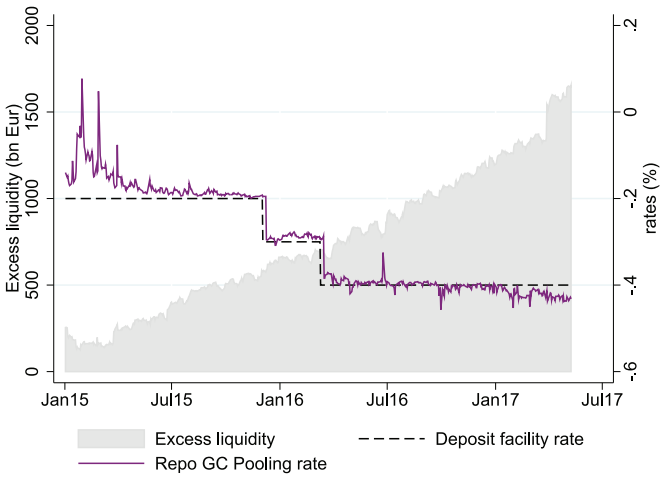


Fig. 2. GC pooling, deposit facility rate, and excess liquidity. *Note:* Excess liquidity computed as (current accounts held at the Eurosystem + recourse to the deposit facility – reserve requirements – recourse to the marginal lending facility). *Source:* ECB's Statistical Data Warehouse and Bloomberg.

−0.40%, a market participant willing to borrow the German Bund maturing on August 15, 2027 and not another bond, might have to accept to lend its cash at −0.50%. This specialness premium is the subject of Sections 2.2 and 2.3.

In the remainder of this Section, we will consider the different possible theoretical mechanisms that could explain how the asset purchases of the Eurosystem caused the decline of repo rates in the euro area.

2.1. The general collateral repo rate and the role of excess liquidity

Several GC rates coexist in the euro area. A common benchmark for the short-term secured funding is the Stoxx GC pooling (hereafter GC pooling).[6] It is secured by a basket of around 3000 securities.[7] GC pooling has declined in absolute terms and also with respect to the DFR (Fig. 2).

A decline in money market rates in the wake of an increase in liquidity[8] does not sound particularly mysterious. The negative relation between excess liquidity and money market rates is well documented both empirically and theoretically. In a corridor system, theoretical works predict that excess liquidity should exert downward pressures on interest rates until they reach the rate at which the central bank remunerates reserves (see, for instance, Ennis and Keister, 2008; Bech and Monnet, 2016). This liquidity effect is a simple way to explain what happened in the first months of 2015 when money market rates decline toward the DFR. In March 2015, at the start of the PSPP, excess liquidity was already elevated, around 200 billion EUR. At this level of excess liquidity, the literature predicts that short-term interest rates should be already close to the central bank DFR and less responsive to a further increase in excess liquidity (Vari, 2019). The situation since the second half of 2015, however, violates this de facto relation between the GC rate and the DFR as repo funds rates started to trade below the DFR (German and French repo funds rates in April and May 2015, respectively).

In the US, Bech and Klee (2011) show that segmentation between banks (which have access to the deposit facility of the central bank) and nonbanks (which do not) in an environment of large excess liquidity drove the effective Fed funds rate below the rate of remuneration of excess reserves. Excess liquidity reinforces the bargaining power of banks that can remunerate the liquidity of nonbanks at a rate lower than what they earn by depositing this liquidity at the central bank, thus earning a profit. Applying this framework to the euro area repo market, where similar segmentation exists, could explain why the differential between GC repo rates and the DFR persists.

In particular, some participants in the GC pooling market do not have access to the Eurosystem deposit facility (e.g., foreign banks). Thus, they are unable to arbitrage the difference between placing their cash at the central bank and lending it in the repo market.[9] Moreover, contrary to previous episodes of central bank liquidity expansion by the Eurosystem, the PSPP is likely to have directly increased cash holdings of nonbanks.[10] Koijen et al. (2017) study how investors rebalanced their portfolios in reaction to the PSPP. In particular, foreign

[6] See ECB (2015b). Stoxx is the name of the company publishing the interest rate. GC stands for general collateral. "Pooling" is a method of collateral management, where the cash-borrower can substitute securities at any time in his collateral pool.

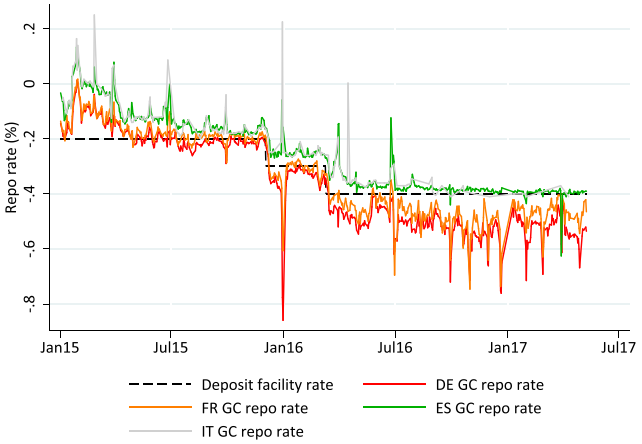
[7] Only securities rated at least A- are eligible. This basket includes debt issued by central governments, regional governments and supranational institutions. Some highly rated covered bonds are also included. Among the seven largest euro area economies, bonds issued by Spain and Italy are not eligible in the Stoxx GC pooling basket. They are, however, eligible in the Stoxx GC pooling extended basket, which trades at levels close to the simple Stoxx GC pooling, also called Stoxx GC pooling ECB basket.

[8] In this paper, we use the term "liquidity" to refer to the amount of central bank liquidity available to banks. This should not be confused with the market liquidity of the securities used in a repo transaction.

[9] This list is public and can be found on the website of EUREX: http://www.eurexrepo.com.

[10] By contrast, the two three-year long-term refinancing operations (LTROs) launched in late 2011 and early 2012 injected liquidity primarily in the banking sector since only euro area banks are eligible to borrow from the Eurosystem; the liquidity might have channeled the financial system differently.

(a) GC repo rates for selected countries



(b) Spread of each GC repo rate against the deposit facility rate and excess liquidity. Data shown up to 1,500 bn euro of excess liquidity.

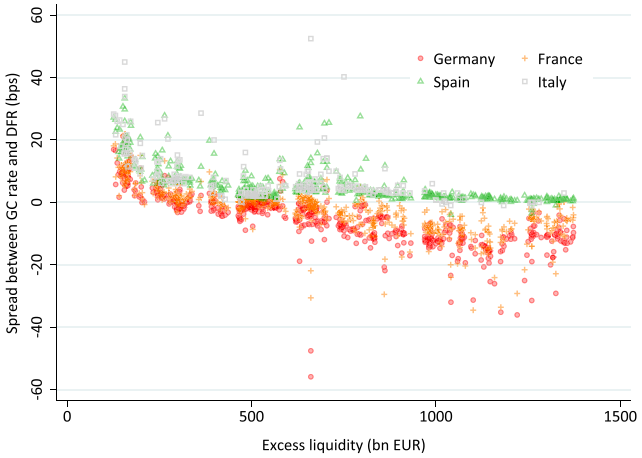


Fig. 3. GC repo rates divergence by jurisdiction. Panel (a) shows GC rates by countries, computed as the daily volume-weighted average of rates on trades made against GC baskets in Brokertec. For sake of clarity, we drop data between the last week of December 2016 and the first week of January 2017. Panel (b) shows a scatterplot of the spread of each country-GC rate against the DFR and the level of excess liquidity.

(that is, non-euro area) investors have been substantial sellers to the program.

2.2. The links between GC rate(s) and SC rates

Besides GC pooling, which has the largest collateral basket, there also exists several country-specific GC baskets: a GC basket containing only German sovereign bonds, another one of French sovereign bonds, etc. We construct the time series (see Fig. 3(a)) of those country-specific GC repo rates from transactions against these baskets made in the repo platform Brokertec.[11] Section 3 describes the database in more details.

We first observe that there is a clear hierarchy between the different repo rates, presumably reflecting credit risk or particular services offered by GC of certain countries.[12] Interestingly, end of quarter and end of year seem to be responsible for heightened volatility, reflecting also sometimes opposite patterns between core and peripheral euro area countries. This strongly suggests that banks swapped

[11] Country-specific GC rates are the weighted average rates of all transactions reported against national GC baskets, irrespective of the maturity of the collateral. We therefore do not distinguish between GC German "Sub ten years" and the GC Germany, including bonds with maturity over ten years.

[12] This could seem surprising given that these transactions are cleared by central counterparties (CCP) (as explained at the beginning of this Section). CCP already apply haircuts that should take into account the difference of credit risk of each underlying collateral. Boissel et al. (2014) suggest that divergence between GC rates of European countries could be explained by the pricing of the tail risk that in some states of the world CCPs might default, letting repo market participants with a direct exposure to collateral credit risk.

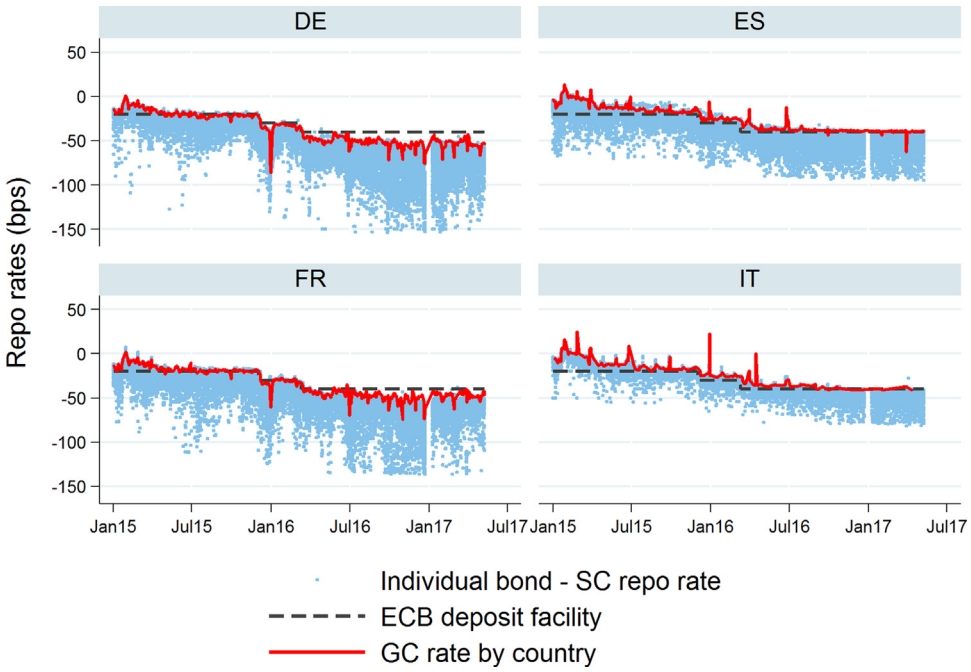


Fig. 4. Euro area's four largest countries GC and distribution of SC repo rates. *Note:* Each dot corresponds to a specific security daily SC repo rate. This SC repo rate is computed as the daily volume-weighted average of SC transactions on each day on this specific security. This is the same figure for all seven countries of our sample in the appendix.

their securities at end of accounting periods. This aspect is shown in the US, for instance, by Duffie and Krishnamurthy (2016) and is related to the implementation of the supplementary leverage ratio (SLR).

Second, we observe that GC repo rates have been diverging since 2016, as shown on Fig. 3(b). Interestingly, GC rates in Italy and Spain seem to remain effectively bounded by the DFR. In Germany and France, GC repo rates trade at significantly lower levels, suggesting that excess liquidity affects differently the different euro area jurisdictions. A simple elasticity analysis suggests that beyond 500 billion euro of excess liquidity, Italian and Spanish GC remain muted and floored by the DFR, while each extra one billion euro of excess liquidity is associated with −1 bps in the German and in the French GC. This makes sense in a world where market participants without access to the DFR have strong preferences to park their liquidity against core countries GC, for instance.

On Fig. 4 we plot country-GC rate versus SC rates for the bonds of the same countries. It shows a large dispersion of SC rates, with some bonds trading sometimes 100 bps below the country-GC rate. In every jurisdiction, most SC repo rates are below the DFR. Some repo rates in Italy and Spain remained above the DFR for longer. Given the smaller share of these two countries in the total of PSPP purchases, less bonds have been purchased by the Eurosystem in those jurisdictions. This is combined with the fact that these sovereigns have a large amount of debt, lower demand from market participants for regulatory reasons, and higher level of risk.

In each country, GC rates behave as the upper envelope of SC rates. This makes perfect sense given that the holder of a bond that could be lent both in a GC basket or in the SC market has no reason go to the GC market if this bond has a specialness premium, and if it can be used to to borrow cash below the GC rate. Conversely, if the SC rate was higher than the GC rate, there would be an arbitrage opportunity. In that case, one could make profit by borrowing the security at the SC rate and lending it at the GC rate.

These observations lead us to consider the following possibility: it could be the case that bonds in some countries are so scarce that they all have values on the repo market. As a result, GC rates do not reflect risk-free funding rates (as it is often assumed in the literature), but instead reflect just the highest SC rates, and are below where the risk-free rate should be (if we were able to observe it). When all bonds are valuable in the SC repo market, the GC rate is not necessary reflecting a risk-free rate and the GC-SC spread (the specialness premium) is not an accurate measure of the value of a bond on the repo market. In our empirical analysis we will therefore use the SC rate instead of the GC-SC spread.

2.3. The effect of bond scarcity on SC repo rates

2.3.1. The theoretical mechanism behind specialness

Following Duffie (1996), we assume that some specific securities are actively sought out in the repo market. This happens, for instance, when a financial intermediary "short-sells" a security (i.e., sells a security he currently does not possess). To deliver the security, the financial

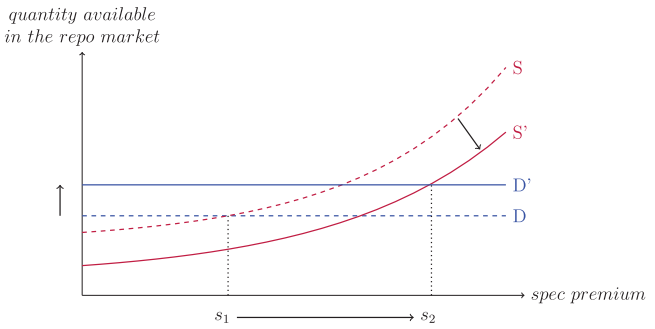


Fig. 5. Impact of supply and demand shocks in the SC repo market.

intermediary might either try to buy it in the bond market or borrow the security in the repo market at the SC rate.[13] The specialness premium is the difference between the GC rate and the SC rate of the security.

A key friction in Duffie's model is that some holders might be unwilling to lend these securities at the GC rate, but only at some lower rate, the SC rate, and thus demand a specialness premium to lend their bonds. The supply curve is therefore upward sloping.[14]

The demand for collateral, in the form of reverse repos, emanates from short-sellers, who must find the securities to avoid failing on their deliveries. Thus, for a given size of short positions in the security market, the demand from shorts is inelastic to the SC rate of the security.[15]

Fig. 5 illustrates the SC repo market supply and demand for a given security. The horizontal axis measures the specialness premium. The vertical axis measures the quantity available for trade in the repo market. Supply and demand of collateral for all possible levels of *Spec premium* are displayed, holding constant the positions of agents in the bond market. Fig. 5 also shows the effect of a reduction of supply and an increase in demand, which is what has happened in the Eurosystem in recent years, as argued in the next section.

2.3.2. Supply and demand shocks in the SC market

Equipped with these theoretical foundations, one can figure out the impact of the PSPP on the repo market.

The Eurosystem announced on January 22, 2015 the expanded Asset Purchase Program (APP)[16] to provide additional monetary policy stimulus to "help to bring inflation back to levels in line with the ECB's objective" and support credit conditions, "a precondition for inflation to return to and stabilize at levels close to 2%."[17] The extended package included for the first time purchases of sovereign bonds from all jurisdictions[18] under the PSPP. Purchases started in March 2015 at a pace of around 50 billion euro a month for euro area government bonds. As of May 2017 (the end of our sample), the Eurosystem held 1500 billion euro of government bonds, among which around 900 billion euro are rated at least single A. The total euro area sovereign bond market represents around 7500 billion EUR, according to the ECB. We argue that the Eurosystem's PSPP probably triggered a rise in short-selling. Indeed, by purchasing bonds on the open market, central banks might directly lead their counterparties to short-sell the bonds to them. Counterparties are then left with a short position.[19]

[13] Failing to return a bond at the term of a repo transaction triggers a complex process in Europe, depending on types of agreements signed by the counterparties, and are largely based on market practices. In the worst case scenario, fail may put a counterparty in default. Most of the time, however, there is a agreement to defer the restitution of collateral. In this case, the repo continues interest-free for the counterparty holding cash. However, as noted by ICMA (see https://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/repo-and-collateral-markets/icma-ercc-publications/frequently-asked-questions-on-repo/40-what-happens-to-repo-transactions-when-interest-rates-go-negative/), negative repo rates may create a pervasive incentive to fail to deliver the collateral. Thus, market practice in CCPs evolved toward passing the negative cost of bearing cash for the failed counterparty to the failing counterparty. Euroclear, for instance, remunerates cash balances over 150 million euro at −70bps since the end of 2016 (see http://www.clearstream.com/clearstream-en/products-and-services/asset-types/cash/a16162/83886), and this cost will be charged to the failing counterparty.

[14] The link between bond outstanding in the outright market and quantities available for lending in the repo market is not necessarily straightforward (see Bottazzi et al., 2012). The total amount outstanding of a given bond is not necessarily made available for loan in the repo market. Conversely, quantity lent in the repo market may also result from reuse. Reuse is the activity performed on the repo market whereby agents having borrowed a security will lend again the collateral.

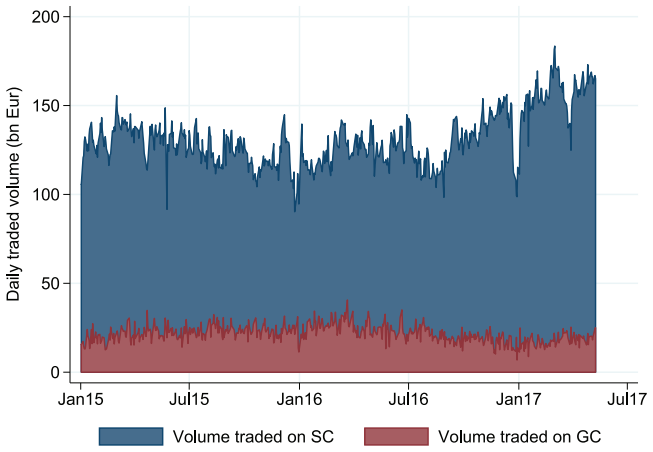
[15] The short-seller would not find it less costly to purchase the security on the outright market. Indeed, the increase in specialness translates into an increase in the price of the security. As holders of the bond trading on special can potentially borrow money below other market rates, the security incorporates an additional value, referred to as "repo dividend" by Fisher (2002). This repo dividend implies that everything else constant, a bond trading on special on the repo market will have a higher price on the bond market.

[16] Expanded APP merged the two existing asset purchase programs–CBPP3 on European covered bonds market and ABSPP on ABS market–with a new program on European sovereign bonds (PSPP). Details can be found on the ECB website here: https://www.ecb.europa.eu/mopo/implement/omt/html/index.en.html.

[17] See https://www.ecb.europa.eu/explainers/tell-me-more/html/asset-purchase.en.html.

[18] As of May 2017, the Eurosystem has not purchased any Greek bonds.

[19] A large part of the literature on short-selling focuses on the so-called on on-the-run bonds, which are special. These bonds are special because they are heavily short-sold by primary dealers to their clients (see, for instance, Duffie, 1996; Fisher, 2002; Krishnamurthy, 2002; D'Amico et al., 2018, among others). Other bonds which are subject to heavy short-selling activity are bonds included in the basket of future contracts and that are the "cheapest to deliver" (Buraschi and Menini, 2002). At last, short-selling is used in anticipation of a decrease in the price of the security.



Source: The euro area collateral data are from Brokertec.

Fig. 6. Daily volumes traded against SC and GC collateral. *Source:* The euro area collateral data are from Brokertec.

On the supply side, several forces could have contributed to decrease the supply of collateral in the euro area. First, the quantity of securities available for lending in the repo market might have decreased. For instance, it seems that many regulatory constraints force financial intermediaries to hold certain bonds and might prevent them from lending these bonds out on the repo market. Those constraints began to enter into force since 2015 onward, and a nonexhaustive list can be found in Appendix A. Several pieces of regulation such as the leverage ratio (LR) or the liquidity coverage ratio (LCR) penalize the use of repos by banks. As a result, banks might not be able to intermediate trades between some of their clients willing to lend securities to the market and institutions that are short of the bonds. Everything else equals, this lack of arbitraging capacity should allow larger specialness premia to persist. The effect of these regulations is even stronger at quarter-ends, when European banks have to comply with regulation and report on the structure of their balance sheet to investors. On those dates, repo activity may shrink significantly (Klee et al., 2016; Munyan, 2015).

3. Data

3.1. Repo transactions data

The repo market represents around 60% of the money market, compared to less than 5% for the unsecured market (ECB, 2017).[20] Within the repo market, the daily turnover of SC (mostly on the MTS and Brokertec platforms) was around 200 billion euro daily in the first quarter of 2017 (Coeuré, 2017a), more than 20 times the size of the GC pooling market (on the Eurex platform).[21] Brokertec is by far the largest of the two platforms dedicated to special trades (Dunne et al., 2013). Overall, we are confident that our database on SC trades covers the largest segment of the euro area money market and the interest rates we observed are the most representative available. We focus on the one-day maturity, the "spot-next" tenor, which is the most traded in our data set (67%).[22]

The raw data report slightly more than five million trades between January 2, 2015 and May 9, 2017, collateralized with 1,282 different International Securities Identification Number (ISIN), representing either a basket (in the case of GC transactions) or specific securities used as collateral. The vast majority of transactions made in Brokertec concerns the SC repo market (87%, on average, during the period), and this share has increased since January 2015 (see Fig. 6).

Almost all transactions in Brokertec are cleared through a central counterparty (LCH Repoclear) in charge of applying a public haircut schedule to the collateral depending on the issuer country and the residual maturity. We will not focus on these haircuts in the paper, as they were relatively stable during our period under review. In any case, as they are defined for each issuer country for given maturities, they will be captured by maturity bucket, issuer country, and time fixed effects in our regressions.

On average, around 170 billion euro were exchanged each day on the period. For each transaction, we have the trade date, the term, the trade volume, the rate, and

[20] The remaining 35% are derivatives (foreign exchange swaps and overnight index swaps). It implies that among non-derivative product, repo represent 92% of the money market.

[21] See also ICMA: http://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/repo-and-collateral-markets/frequently-asked-questions-on-repo/41-mapping-the-interdealer-european-repo-market/. The secured market represents by far the largest market segment of euro area money markets, with 41% of total turnover in 2015, while the unsecured market segment accounts for only 4% of the market (ECB Euro Money Market Survey, 2015). The infrastructures on which the euro-secured market operates are detailed in Mancini et al. (2016). It can be broken down among bilateral, triparty, and CCP-based operations. As of 2013, trading via CCPs stands for 71% of total market, up from 42% in 2009. Also, the vast majority of repos with government bonds and other relatively safe securities transit via CCPs.

[22] The spot-next tenor covers transactions that have a one-day maturity and where the first leg of the agreement is settled two business days after it is concluded.

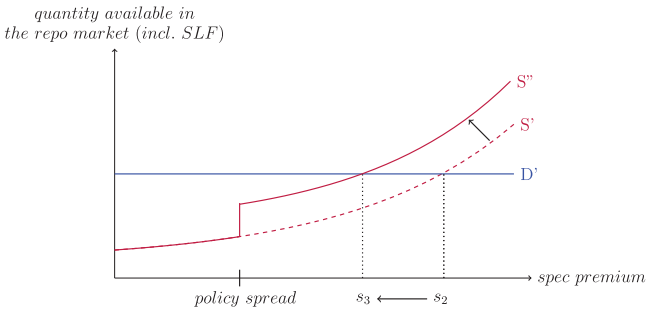


Fig. 7. Impact of the introduction of the SLF on the SC repo market. *Note:* We illustrate the impact of the introduction of a securities lending facility (SLF). Above a given "policy rate" announced by the central bank, which corresponds to a level of specialness premium, bonds are lent at the SLF against GC–or less special–collateral. This shifts upward the supply curve in an hypothetical repo market constituted of the private repo and SLF. As a consequence, after its introduction, the specialness premium at equilibrium decreases from s_2 to s_3. This result is in line with the theoretical framework built by Duffie and Krishnamurthy (2016) on the US money market. In practice, in the SLF (against securities as collateral) of some euro area central banks (Germany, France, Netherlands, for instance), any monetary policy counterparty can borrow the security at the central bank against a GC security, for a quantity not above 200 million EUR, at a policy spread that is at least equal to ten bps below the GC rate.

the collateral identified by a unique ISIN. We focus on the SC repo transactions of the seven largest euro area economies[23] and exclude bonds issued by supranationals and keep only securities issued by central governments.[24] As the majority of transactions (67%) has a maturity of one day and is settled two days after the trade (spot-next), we also focus on this tenor.

As the highest frequency of our other data is daily, we compute for each security a daily repo rate $Repo\,rate_{i,t}$, which is the average rate of repo transactions $Repo\,rate_{i,\theta}$ on this security at date t, weighted by volumes exchanged.

$$Repo\,rate_{i,t} = \left[\frac{\sum_{\theta=1}^{n} Repo\,rate_{i,\theta} \times Volumes_{i,\theta}}{\sum_{t}^{n} \times Volumes_{i,t}}\right]_t. \qquad (1)$$

Fig. 8 shows the distribution of the SC repo rates at the bond level by country between January 2, 2015 and May 9, 2017.

Unlike other studies (e.g. D'Amico et al., 2018; Corradin and Maddaloni, 2017), we do not use the specialness premium, computed as the spread of SC repo rates against a GC rate. While most studies use this spread to measure the extent of the specialness we do not find it suitable in our case. Contrary to previous works that usually focus on a single debt market (e.g., the US, the Italian market, etc.), we compare seven different countries, which might have very different levels of GC rates. For instance, some platforms allow to trade a repo secured by an unspecified German government bond. This GC country-specific rate might not be the same as a GC rate against an Italian collateral. It is likely that the rate varies depending inter alia on the credit risk associated with sovereign debt. A market participant willing to lend out its cash would probably not lend at the same rate knowing that he could get any German collateral or a bond issued by another country. In most of our specifications, we will control for the general level of interest rates through our time fixed effects, and more specifically the levels in each countries, through the country-time fixed effect. Thus, having SC rates or spread between a GC and SC rates at the left hand-side would not yield different results, as GC would be captured by the country-time fixed effects.

3.2. Eurosystem's purchases and bonds characteristics

For the Eurosystem purchase program, we use proprietary data of all PSPP transactions made by the Eurosystem, at the security-day level. For each PSPP transaction, we have the trade and settlement dates, the book value, the nominal amount, and the ISIN identifier. The same security might be purchased several times during a day. When this is the case, we sum the purchases made during the day. Then, we compute the cumulative sum of PSPP transactions at each date and the ratio of this cumulative purchases on the nominal outstanding of the bond (i.e., the share of this bond held by the Eurosystem under its PSPP program).

We use of the Securities Holdings Database (SHS) to compute for each bond the structure of its detention among institutional investors to explore whether the holding structure correlates with specific patterns of collateral demand and specialness. A detailed description of the database is given by Fache Rousová and Rodríguez Caloca (2015). We are particularly interested in the detention by inelastic investors, unlikely to lend their bond holdings in the repo market. In the spirit of Koijen et al. (2017), we call inelastic investors insurance companies and pension funds, households, nonfinancial corporations, and governments. Elastic investors include banks, mutual funds, and the foreign sector. As with the PSPP, we compute the share of the nominal outstanding amounts held by these two investors' groups.

For each security, we complement daily repo and daily PSPP purchases data with data on bond characteristics, retrieved either through the EADB database (Eurosystem's eligible assets database) or Bloomberg (nominal outstanding, issue and maturity dates, issuer rating, coupon rate). We also retrieve from Bloomberg and the ECB macro variables such as daily excess liquidity, Overnight Index Swaps

[23] Germany (DE), France (FR), Italie (IT), Spain (ES), Netherlands (NL), Austria (AT), Belgium (BE).

[24] Securities issued by the German agency KFW or the French agency CADES are excluded.

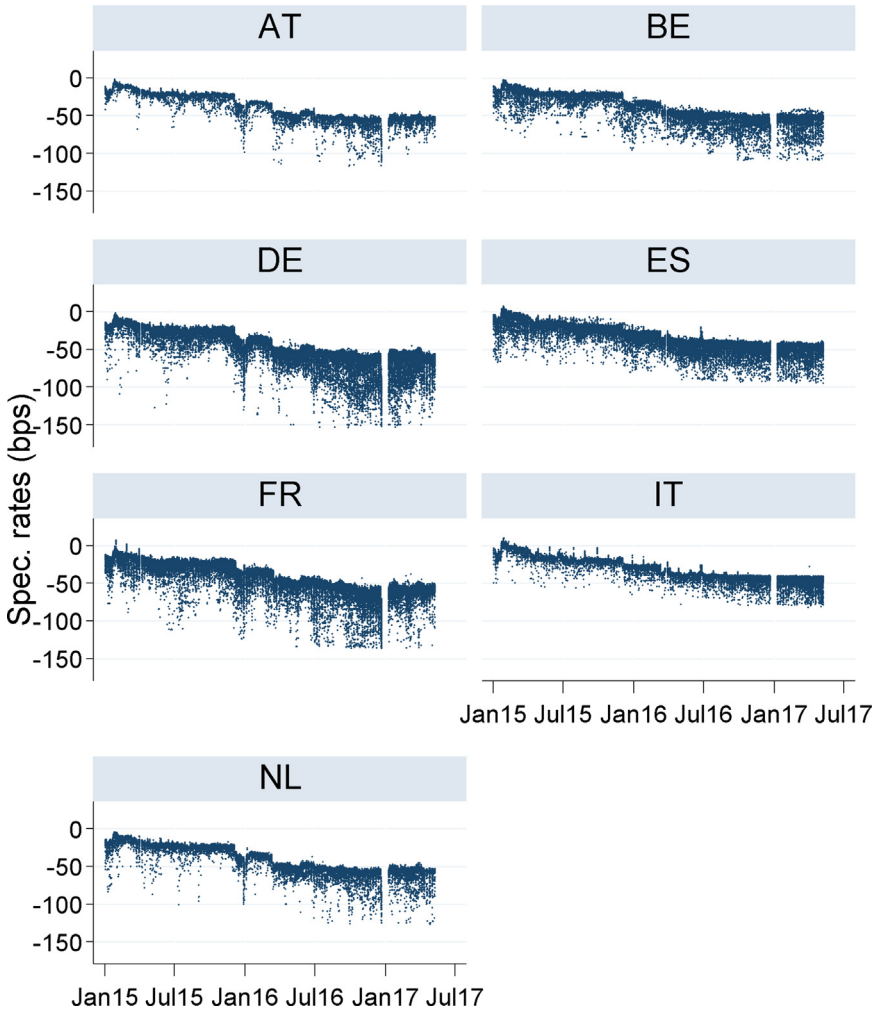


Fig. 8. Distribution of SC repo rates by bond and by country. We exclude the last week of December 2016 and the first week of January 2017 to exclude year-end volatility. Each point represents the daily volume-weighted rate traded on the repo special market and on a unique special bond.

(OIS) rates, European stocks volatility index VSTOXX, and the sovereign Credit Default Swaps (CDS).

3.3. Panel description

For each country, we remove the first and the last percentile of specialness rates to deal with outliers, and we drop the last week of December 2016 and the first week of January 2017 because of heightened volatility at year-end. The results are virtually unchanged when we include the outliers and observations from 12/23/2016 to 01/07/2017. The cleaned sample consists of 203,203 observations for 823 individual securities. Our panel remains unbalanced, as all bonds do not necessarily trade on the repo market on each date.[25]

[25] Due to the presence of singletons, 201,855 observations are usable with our full fixed effects specifications.

Table 1 gives the main descriptive statistics of variable we use in our empirical exercises.

Fig. 8 shows the daily distribution of these repo rates by country.

4. Empirical strategy

4.1. OLS specifications

The aim of this paper is to understand the behavior of special repo rates in the euro area. The left hand-side variable is therefore the SC repo rate for a bond (identified by its ISIN code) on a given day, constructed from Brokertec, as explained in the previous section. Our main independent variable is purchases of bonds by the Eurosystem under the PSPP. For each bond, we construct a variable, "PSPP," which is equal to the ratio of PSPP purchases to the total amount outstanding both expressed in nominal

Table 1
Cleaned sample, January 2, 2015 to May 9, 2017.

Variable	Mean	min	max	sd	obs
Repo rate (bps)	−40.48	−153.79	10.00	20.42	203,203
Share held PSPP (%)	6	0	33	8	203,203
Time-to-maturity (yr)	6.99	0.01	70.05	8.59	203,203
Nom. outstanding (bn EUR)	14.52	0.00	43.19	8.26	203,203
Share held by inelastic investors	0.21	0.00	0.90	0.17	199,885
ISIN-daily volume in repo (mn EUR)	294	1.00	7571	453	203,203
Credit rating (1=AAA)	2.96	1.00	8.00	2.64	203,203

values.[26] If the Eurosystem has bought 20% of a given bond under the PSPP, PSPP is equal to 20 for this bond.

In line with the literature, we run our regressions in first differences to deal with the persistence of these variables.[27]

We include bond fixed effects, which capture inter alia the original maturity of the bond, its coupon rate, whether it is inflation linked, and so on. We also include country-maturity bucket-time fixed effects, which capture macro variables (e.g., the amount of excess liquidity), the information about the issuer (e.g., credit rating), and possibly effects related to maturity buckets in this country (crucially haircuts, as discussed above). We define five maturity buckets (i.e., less than one year, one to two years, two to five years, five to ten years, and more than ten years) and made sure that our results are robust to a narrower or wider definition. To account for the possibility that error terms might be correlated across similar bonds in terms of maturity or country of issuance, we cluster our standard errors at the maturity-issuer level.

Our baseline OLS regressions is as follows:

$$\Delta Repo\,rate_{i,t} = \beta\,\Delta PSPP_{i,t} + FE_i + FE_{country,bucket,t} + \epsilon_{i,t}. \tag{2}$$

Strictly speaking, these specifications test whether the PSPP pushes down repo rates, controlling for the DFR with time fixed effects. As shown in Section 2.1, at the beginning of our sample, just before the start of the PSPP, a moderate amount of excess liquidity had already led to a decline of all interest rates close to the DFR. Under such circumstances, showing that the PSPP pushes down repo rates is equivalent to show that the PSPP pushes repo below the DFR.

As in D'Amico et al. (2018), we allow for different types of bonds to be impacted differently by PSPP purchases. It is well documented, for instance, that on-the-run bonds (the last issued bond of a given maturity in a given country) is in high demand from a certain number of investors and is heavily sold short (see, for instance, Duffie, 1996; Fisher, 2002; D'Amico et al., 2018). As a result, repo rates for on-the-run governments bonds might be lower in level (this effect cannot appear in first differentiated regressions), and the sensitivity of repo rates for on-the-run treasuries to PSPP purchases might be larger. We therefore construct a dummy variable equal to one whenever a security is on the run in a given country and equal to zero otherwise. Symmetrically, we construct a variable off-the-run equal to one minus on-the-run. Then we interact these dummy variables with the PSPP purchases. This regression becomes

$$\begin{aligned}\Delta Repo\,rate_{i,t} = {} & \beta_1 \text{on} - \text{the} - \text{run} * \Delta PSPP_{i,t} \\ & + \beta_2 \text{off-the-run} * \Delta PSPP_{i,t} + FE_i \\ & + FE_{country,bucket,t} + \epsilon_{i,t}.\end{aligned} \tag{3}$$

Similarly, we construct a dummy variable equal to one when the bond is a cheapest-to-deliver bond in a future contract and equal to zero otherwise.[28] We also interact these dummy variables with the first difference of PSPP, the percentage of a given bond issue bought by the Eurosystem. We run other regressions with interactions. We notably look at the proportion of bonds held by "inelastic investors." These are investors we suspect to be relatively inelastic to changes the repo market. At last, we interact our measure of asset purchases with country dummies (to explore the potential heterogeneous effects of the PSPP for each country).

Another set of regressions intends to identify the effect of time-varying characteristics common to all bonds. We therefore remove the time or country-time fixed effects and replace them with macro variables, such as excess liquidity, Euro Overnight Index Average (EONIA) swaps, the GC pooling, the VSTOXX, CDS spreads, etc. We then run regressions of the following form:

$$\begin{aligned}\Delta Repo\,rate_{i,t} = {} & \beta_1 \Delta PSPP_{i,t} + \beta_2 \Delta Excess\ liquidity_t \\ & + \beta_3 \Delta OIS_t + \beta_4 \Delta GC\ pooling_t \\ & + \beta_5 \Delta VSTOXX_t + \beta_6 \Delta CDS_t \\ & + \beta_7 SLF\ vs\ cash + \beta_8 End_{m,q} + FE_i + \epsilon_{i,t}.\end{aligned} \tag{4}$$

The *SLF vs cash* dummy captures the period of implementation of the securities lending facility against cash. From December 15, 2016, under this facility, the Eurosystem lent part of the securities purchased as part of the

[26] Outstanding amounts are taken from the ECB eligible assets database (EADB) at daily frequency and take into account debt management operations such as buybacks.

[27] As explained by D'Amico et al. (2018), taking first differences also reduces concern of serial correlation. We nevertheless perform tests of serial correlation as an additional check.

[28] An agent having sold a future contract on the five-year German bond has the possibility to deliver several bonds at the contract maturity date. The cheapest-to-deliver is, among the bonds allowed for delivery, the bond that offers the highest return for someone having sold the future contract. It is therefore in high demand on the repo market. Traders borrow it to deliver it (see Buraschi and Menini, 2002). We expect this type of bonds to have a less elastic supply and thus to be affected more heavily by PSPP purchases.

Table 2
Securities lending facilities (SLF) against security conditions.

Country	SLF cost, to borrow a specific security	Limits
Germany	GC rate minus some fixed (confidential) spread	200 mln EUR/security
Netherlands	GC rate minus 10 to 25 bps	200 mln EUR/security
France	GC rate minus 10 to 25 bps	200 mln EUR/security
Italy	The special repo rate for that security minus an additional penalty of 10 bps	200 mln EUR/security
Spain	The most penalizing of these two rates: special repo market rate for that security or the GC rate minus 10 bps	200 mln EUR/security
US	Minimum bid rate of 5 bps	90% limit on holdings

Table 3
Securities lending facilities (SLF) against cash conditions.

Country	SLF cost, to borrow a specific security against cash	Limits
Eurosystem	−30 bps below the ECB deposit facility rate	50 bn euro in total

Source: Central banks' respective websites.

PSPP against cash (limited to a total usage by counterparties at 50 billion EUR – see Table 3). $End_{m,q}$ is a dummy taking one at accounting reporting dates, namely end of month and end of quarter that are responsible of spikes in the repo rates times series. While this is not the core subject of this paper, Appendix A provides details on how regulations may be related to these calendar dates volatility.

4.2. Addressing potential reverse causality

The OLS regressions presented above are standard in the empirical literature on specialness. They are also useful because they provide us with a lower bound of the effect of the PSPP on repo rates. However, we suspect that they could be subject to an endogeneity bias and, more specifically, to reverse causality. Such bias would underestimate the effect of the PSPP on repo rates.

The main source of reverse causality bias may come instead from the guidelines governing the PSPP purchases themselves. ECB official statements confirm that PSPP purchases may take into account specialness. For instance, ECB board member Benoit Coeuré declared:

"One key principle underlying the implementation of the PSPP is [...] market neutrality of our operations. [...] To this end, we will take particular care to avoid exacerbating any existing market frictions. More specifically, we will try to avoid, to the extent possible, purchasing specific securities such as current cheapest-to-deliver bonds underlying futures contracts, securities commanding special rates in the repo market as a sign of temporary scarcity, and other assets displaying significant liquidity shortages."[29]

[29] "Embarking on public sector asset purchases", speech by Benoit Coeuré, member of the executive board of the ECB, at the Second International Conference on Sovereign Bond Markets, Frankfurt, March 10, 2015.

To deal with this endogeneity concern, we propose a new instrumental variable. We take advantage of the legal and technical rules that the Eurosystem imposes on the PSPP purchases. In particular, we make use of three rules.

Rule 1: the Eurosystem may not buy bonds below a certain residual maturity. This minimum maturity was fixed at two years initially[30], and at one year subsequently, from January 2017 onwards.[31]

Rule 2: the Eurosystem may not buy bonds that have a residual maturity greater than 30 years.[32]

Rule 3: the Eurosystem may not buy bonds around their issuance or reissuance dates. It also refrains from buying bonds of similar residual maturity. This rule intends to avoid any monetary financing of the government.[33]The ECB Governing Council states that it applies a blackout period (i.e., a period during which securities could not be bought), was considered to be a safeguard to preserve the distinction between the primary and the secondary markets. It would also be applied for the neighboring securities along the yield curve. Such a provision would be in line with earlier practice to ensure compliance with the monetary financing prohibition laid down in the treaty.[34]

These rules were put in place before the start of the program for reasons unrelated to the repo market (see above) and before specialness became so prevalent in the euro area bond market. They apply exactly in the same way to any bond, irrespective of its repo rate or the repo rates of the neighboring bonds. Thus, these rules are a convenient source of exogenous variations in the amount of securities bought by the PSPP. Combining these rules allows us to predict that a bond will not be purchased if its residual maturity is noneligible or if it is affected by the blackout period.

To identify the blackout period, we retrieve every issuance and reissuance events in the European government bonds market. We define the bonds affected by blackout periods and its time frame similarly to De Santis and Holm-Hadulla (2017), although we use it in a different way to build our instrument. To ensure that our instrument affects repo rates only through PSPP purchases and satisfies the exclusion restriction, we use only the blackout period for "the neighboring securities along the yield curve." We do not use the blackout period for the securities that have directly been (re)issued. This is because securities typically become more special in the repo market around their own (re)issuance dates. This is well described, for instance, by D'Amico et al. (2018).

The first stage predicts $\widehat{\Delta PSPP}_{it}$ based on the instrument $Eligible_{i,t}$ that takes the value one whenever the three eligibility rules above are satisfied, and zero otherwise. The first stage equation writes as:

$$\widehat{\Delta PSPP}_{it} = \beta_1 Eligible_{it} + FE_i + FE_{country,bucket,t} + \epsilon_{it}. \qquad (5)$$

[30] ECB (2015c).
[31] ECB (2015c).
[32] ECB (2015c).
[33] The Eurosystem considers that buying on the secondary market a bond just before or just after it is issued is equivalent to buying it on the primary market, something prohibited by the Lisbon Treaty and before it by the Maastricht Treaty.
[34] ECB (2015a).

Table 4
Effect of PSPP purchases on SC repo rates. This table shows the impact of PSPP purchases on "Spot-next" SC repo rates. All variables are in first difference. PSPP variable is the first difference of the share of the bond outstanding held by the PSPP. We use various set of fixed effects. The number of observations may change due to singletons. Standard errors are clustered at the maturity bucket-country level.

	(1) SC repo rate	(2) SC repo rate	(3) SC repo rate
PSPP	−0.656***	−0.765***	−0.781***
	(0.112)	(0.0914)	(0.0960)
Bond FE	Yes	No	Yes
Country-bucket-time FE	No	Yes	Yes
R^2	0.004	0.509	0.512
Observations	202,323	201,864	201,855

Standard errors are in parentheses, clustered at the maturity-country level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5
Effect of PSPP purchases on SC repo rates, differentiated effects. In this table we use various interactions terms to account for possible heterogeneous marginal effects according to bond characteristics. The PSPP variable is the share of the bond outstanding held by the PSPP. All variables are in first difference. Inelastic and elastic refer to the share of each security held by specific types of investors (see Section 3.2). The "cheapest" dummy identifies bonds that are cheapest-to-deliver bonds in future contracts.

	(1) SC repo rate	(2) SC repo rate	(3) SC repo rate	(4) SC repo rate
PSPP	−0.781***			
	(0.0960)			
PSPP × on-the-run dummy		−1.163***		
		(0.173)		
PSPP × off-the-run		−0.583***		
		(0.101)		
PSPP × cheapest dummy			−1.407***	
			(0.526)	
PSPP × not cheapest			−0.776***	
			(0.0967)	
PSPP inelastic				−1.778***
				(0.601)
PSPP elastic				−0.476***
				(0.148)
Bond FE	Yes	Yes	Yes	Yes
Country-bucket-time FE	Yes	Yes	Yes	Yes
R^2	0.512	0.512	0.512	0.504
Observations	201,855	201,855	201,855	198,711

Standard errors are in parentheses, clustered at the maturity-country level. + $p < 0.15$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5. Results

Our results clearly confirm the effect of the PSPP on repo rates. Table 4 displays our baseline OLS regressions, showing the effect of PSPP purchases (as a share of the outstanding amount) with different set of fixed effects. As expected, coefficients are negative and strongly significant. It implies that the higher the amount purchased by the Eurosystem of a given bond on a given day (scaled by the total amount outstanding), the lower the rate of this bond on the repo market. The magnitude and significance of coefficients is little affected by the inclusion of fixed effects. Looking at the third column of Table 4, one can see that buying 1% of the total outstanding (that would represent, on average, 150 million) would result in a decrease of 0.78 bps of repo rates. The economic importance of the effect is in line with the literature. It is above the estimates found for the US market by D'Amico et al. (2018) and below those of Corradin and Maddaloni (2017) for the Italian repo market.[35]

It is very likely that the effect of bond purchases on repo rates is heterogeneous, depending on the characteristics of the bond. Therefore we allow for these heterogeneous effects to show up by interacting the variable PSPP with different dummy variables. The second column of Table 5 shows the effect of PSPP purchases on on-the-run securities (most recently issued) *versus* off-the-run securities. As predicted by theory, on-the-run securities are more affected by central bank assets purchases than other securities, being also the most liquid

[35] These differences could be related to the securities lending program of the central banks when they conduct the purchases, as discussed in Section 6.

Table 6
Effect of PSPP purchases and excess liquidity on SC repo rates. This table reports the estimation of specification 4. All variables but dummies are in first difference. Column 1 recalls the baseline with bond and time fixed effects. In column 2 and 3 we remove the time fixed effects and introduce macro variables. In column 4 we introduce the interaction between excess liquidity and the percentage of foreign selling to the PSPP, as proxied by Securities Holdings Statistics data and explained Section 3.2.

	(1) SC repo rate	(2) SC repo rate	(3) SC repo rate	(4) SC repo rate
PSPP	−0.781***	−0.693***	−0.670***	−0.668***
	(0.0960)	(0.108)	(0.111)	(0.111)
Excess liquidity (excl. MRO and LTRO)		−0.0468***	−0.0469***	−0.0404***
		(0.00311)	(0.00308)	(0.00381)
Excess Liq. × Pct foreign selling				−0.0176***
				(0.00435)
Pct selling by foreign				−0.0966
				(0.0850)
MRO and LTRO		−0.0666***	−0.0664***	−0.0676***
		(0.00647)	(0.00639)	(0.00653)
GC pooling		0.646***	0.644***	0.645***
		(0.0291)	(0.0293)	(0.0293)
End of month		−1.347***	−1.320***	−1.323***
		(0.297)	(0.301)	(0.301)
End of quarter		−0.968***	−0.989***	−0.970***
		(0.320)	(0.324)	(0.325)
Last day of maintenance period		0.00117***	0.00100***	0.000847***
		(0.000145)	(0.000106)	(0.000134)
VSTOXX volatility		−0.00759**	−0.00211	−0.00253
		(0.00311)	(0.00286)	(0.00284)
CDS France		0.0187***	0.0195***	0.0235***
		(0.00616)	(0.00644)	(0.00709)
CDS Italy		−0.0105***	−0.0106***	−0.0106***
		(0.00317)	(0.00317)	(0.00317)
CDS Spain		0.0798***	0.0796***	0.0789***
		(0.00489)	(0.00490)	(0.00489)
Swap OIS 5-year		−0.546	−0.585	−0.822
		(0.502)	(0.506)	(0.511)
SLF cash dummy		0.591***	0.763***	0.719***
		(0.115)	(0.0822)	(0.0921)
Day and month dummies	No	Yes	Yes	Yes
Bond FE	Yes	No	Yes	Yes
Country-bucket-time FE	Yes	No	No	No
R^2	0.512	0.067	0.070	0.070
Observations	201,855	201,600	201,592	201,592

Standard errors are in parentheses, clustered at the maturity-country level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

and therefore most likely to be sold short (Duffie, 1996). The effect is around twice as large, in line with the estimates of D'Amico et al. (2018) for the US market for on-the-run *versus* off-the-run securities. Similarly, looking at the third column of Table 5, one can see that the so-called cheapest-to-deliver securities (which are usually more heavily short-sold than other securities) are once again more affected by the PSPP than other securities.[36] In the fourth column, we explore the effect of the PSPP depending on the type of investors holding the bond. In line with theory we find that bonds held by investors relatively inelastic to repo market conditions (such as pension funds, households, nonfinancial corporations, and governments) are more sensitive to asset purchases. Purchasing 1% of the outstanding amount leads to a decline of 1.8 bps for a bond that is wholly held by inelastic investors. This is due to the fact that those investors will not arbitrage the specialness premium when it starts to rise. At the other extreme, purchasing 1% of the outstanding amount of a bond held completely by elastic investors leads to a decline of only 0.48 bps. One interpretation of this result is related to differentiated effects of PSPP purchases when the purchased bond is held in inventories by the direct counterparties of the central bank (i.e., banks), as opposed to the case when the counterparties do not hold the bond. Let us assume the purchased bond is held by inelastic investors (i.e., insurance companies, for instance). In this case, the purchased bond may be delivered to the central bank by its regular bank counterparty through a short-sale and then covered in the SC repo market.

To isolate time-varying factors that can affect repo rates, we remove time fixed effects. Results are shown

[36] Strictly speaking, one should add the dummy variables on-the-run and cheapest-to-deliver separately from their interaction terms. In practice, the dummies are not significant and do not change the results. Skipping them allows us to lighten the table. Results including them are available upon request. This problem does not arise in the last two columns of Table 5 because the variable original maturity and the country dummy variables without interactions are already contained in the bond fixed effects.

in Table 6. The first column recalls our benchmark regression with bond and country-time fixed effects. The following three columns run regressions with time-varying variables, with different set of fixed effects (but no time fixed effects). The results indicate that excess liquidity has a negative effect on repo rates. For one additional billion euro of excess liquidity, the SC repo rate for any given bond declines by 0.022 bps. This estimate implies an average effect on SC rates of −22 bps in the special repo rate for 1000 billion euro of excess liquidity created through asset purchases.

Over the sample period, excess liquidity increased by 1.3 trillion euro, meaning that, on average, excess liquidity contributed to lowering the whole distribution of repo rates by −28.6 bps. The effect of excess liquidity seems to be as large as the effect of individual bond scarcity. Regarding this second effect, given that, on average, individual bonds holdings have gone from 0% to 33%, it implies an effect of $33 \times -0.78 = -25.8$ bps. In principle, our OLS estimates on excess liquidity could be biased due to reverse causality if the Eurosystem reacted to decreasing repo rates by slowing its bond purchase program. Our estimate of the effect of excess liquidity on repo rates should therefore be considered as a lower bound of the true effect. The magnitude of this bias should, however, not be overstated. Excess liquidity is a variable that is determined by the purchases of all bonds, and it is virtually unaffected by the repo rate of one bond. One can see that the coefficient associated with PSPP is closer to zero (−0.78 *versus* −0.69) when macro variables are used than when time maturity-country-time fixed effects are used, suggesting a possible omitted variable bias. The coefficient associated with excess liquidity is also likely to underestimate its effect of repo rates.

Interestingly, excess liquidity created through MRO (main refinancing operations) and LTRO seems to also depress repo rates. An explanation could be the following. When LTROs and MROs increase, so does the amount of collateral that banks pledge to the Eurosystem. This leads banks to withdraw collateral (including government bonds) from the stock of collateral available for lending and thus lowers supply on the SC repo market.[37]

As explained in Section 2, the impact of excess liquidity could be due to the fact that PSPP purchases place cash in the hands of agents who have no access to the deposit facility of the Eurosystem. The increasing holdings of cash by foreign counterparties as a result of the PSPP has been extensively shown by Coeuré (2017b) and Avdjiev et al. (2019). Moreover, Koijen et al. (2017) and Koijen et al. (2018) show that the foreign sector was the main sector selling bonds to the PSPP. We investigate indirect evidence of segmentation using the ECB SHS.[38] We use an aggregate portfolio rebalancing measure by sector–as computed in Koijen et al. (2017, 2018)–to determine which types of investors sold their bonds to the PSPP. We look at the quarterly amounts sold of eligible government bonds by all sectors and compute the share of sales imputable to the foreign sector. Our measure goes from zero (no bonds were sold by the foreign sector during that quarter) to one (all bonds sold to the Eurosystem were sold by the foreign sector), and we interact this measure with excess liquidity. We name this variable "*Pct foreign selling.*"[39] We expect the coefficient of this interaction to be negative given that the more the foreign sector sold, the more cash needs to be placed by agents without access to the deposit facility and the larger the effect of excess liquidity be on repo rates. In column 4 of Table 6, we introduce this interaction between excess liquidity and Pct foreign selling. This coefficient can be interpreted as the additional effect of excess liquidity when foreigners have been selling to the PSPP. This coefficient has the expected sign (negative) and is statistically significant and large economically: the effect of one billion of excess liquidity injected on repo rates is increased (made more negative) by 0.0176 bps from 0.0404, or an increase of 44%.

We control for possible seasonality patterns with month and day dummies and also for the last day of the ECB maintenance period. Both end-of-month and end-of-quarter dummies' coefficients are negative and highly significant. This might reflect window dressing by financial institutions, in particular from banks, around accounting and regulatory reporting dates. First, financial institutions might be willing to hold high-quality liquid assets (HQLA) on their balance sheet to improve their regulatory ratios such as the LCR. To hold these bonds, they avoid lending them during reporting dates, hence reducing their supply on the SC repo market. In Duffie's model, specialness arises precisely because some agents are unwilling to lend their bonds. Fig. 6 suggests that these dynamics might have been at play at least at year-ends, noticeable in the daily volumes exchanged on the SC market. Second, banks have incentives to deleverage before having to report the size of their end-of-period balance sheet. Lending securities on the SC market, or intermediating such lending, increases leverage (banks have to borrow cash in any case when they engage in such an activity). Appendix A provides details about each kind of regulatory constraints. In particular, calendar dates effects can be related to window dressing around LCR and LR reporting dates.

The *SLF vs cash* dummy corresponding to the period of implementation of the facility against cash collateral (from December 15, 2016) is associated with alleviated pressure on the repo market, consistent with theory. Yet it should be stressed that this period might also see other changes that we have not identified. Thus, the interpretation of the coefficient should be particularly prudent.

We then turn to our regressions that use our instrument. We run the same regressions as in Table 4, now

[37] Banks have to provide collateral as a guarantee to borrow from the Eurosystem.

[38] We are not aware of any existing data set that would enable us to test directly the effect of segmentation on the repo market (i.e., the identity of Eurosystem counterparties for the PSPP and their activities on the repo market).

[39] We focus on the foreign sector as the biggest seller to the PSPP. Results hold when we include other financial institutions without direct access to the deposit facility, namely money market funds. This was not conclusive for other nonbank financial institutions like insurance companies, possibly because many of them have in fact an access to the deposit facility through a parent bank (e.g., AXA bank, Allianz bank, etc).

Table 7
Effect of PSPP purchases on SC repo rates (IV). This table shows the instrumented version of our baseline regression in Table 4. The Eligibility instrument is the interaction of a dummy that takes one if the bond is in an eligible maturity at date t times a dummy that takes one if the bond is not affected (as a "neighboring bond") by a blackout period. The first column shows the first stage, while the other columns show the second stages introducing fixed effects.

	(1) 1st stage	(2) 2nd stage	(3) 2nd stage
Eligibility	0.0934***		
	(0.00710)		
PSPP		−4.723***	−4.994***
		(1.362)	(1.246)
Bond FE	Yes	No	Yes
Country-bucket-time FE	Yes	Yes	Yes
Adjusted R^2	0.106	0.448	0.447
F	173.3	12.02	16.06
Observations	201,855	201,864	201,855

Standard errors are in parentheses, clustered at the maturity bucket level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

using a 2SLS procedure, where we instrument $\Delta PSPP_{i,t}$ with $Eligible_{i,t}$. As expected, the effect of central banks' asset purchases are now estimated to be much larger. After controlling for fixed effects, column 3 of Table 7 indicates that purchases of 1% of the amount of bond outstanding by the central bank decreases repo rate by about 5 bps, compared to 0.78 estimated previously. This result underscores the importance of our instrument: once endogeneity is properly accounted for, the effect of the PSPP on the repo market is about sixfold higher. This would suggest that absent the ECB market neutrality rules outlined above (e.g., avoid purchasing the bonds in highest demand on repo market, etc.), the impact on repo rates would have been largely higher than observed.

We run several tests on the first stage of our 2SLS regression. First, we confirm that in the first stage, the coefficient associated with $Eligible_{i,t}$ (first column in Table 7) is positive and significant, as one would expect. Second, we look at the F-statistic (equal to 170) to make sure it is above the level suggested by the rule of thumb (10). We checked the Stock-Yogo critical values and the Kleibergen test, as well as Olea and Pflueger (2013) test, robust to heteroskedasticity in the data.[40] All tests strongly reject the weak instrument hypothesis.

If specialness were correlated with maturity, our exclusion restriction would be violated.[41] This is why we have run a robustness test for the exclusion restriction and make use only of rule 3 in the first stage of our 2SLS (not using rule 1 and 2). It turns out that results (see Table 8) are only slightly changed, and if anything, the effect of the PSPP turns out to be even stronger.

We also run several robustness checks, shown in Table 9, to ensure our results are not driven by a particular time frame or by our procedure to eliminate outliers. In the first column we exclude the first semester of 2015

[40] We thank an anonymous referee for the suggestion to use this test.

[41] This could be the case for instance if residual maturity were correlated with becoming the cheapest to deliver bond in futures contracts. We thank an anonymous referee for rising this potential issue.

Table 8
Effect of PSPP purchases on SC repo rates IV - robustness test with blackout instrument only.

	(1) 1st stage	(2) 2nd stage	(3) 2nd stage
Blackout	0.0872***		
	(0.00731)		
PSPP		−6.428***	−5.879***
		(1.659)	(1.575)
Bond FE	Yes	No	Yes
Country-bucket-time FE	Yes	Yes	Yes
Adjusted R^2	0.106	0.440	0.443
F	142.4	15.02	13.94
Observations	201,855	201,864	201,855

Standard errors are in parentheses, clustered at the maturity bucket level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

on the account that the program only starts in March and money market rates are rather volatile during this period. Then, in the second column we exclude the whole year 2015. In the third column, we include the outliers and the period of late 2016 early 2017. At last, in the fourth column we remove inflation linkers. Our results are little affected by these changes, and thus we consider our results robust to these changes. We also check our results still hold on subsets of countries, running, for instance, our baseline regression only with German and French government bonds. The significance and magnitude of the coefficients are preserved.

6. Implications for monetary policy

Our results suggest that the PSPP has depressed repo rates by intensifying the scarcity of bonds and by increasing the amount of excess liquidity. Both effects raise a number of monetary policy issues.

6.1. *Should specialness* per se *be a concern at all?*

When discussing normative considerations around specialness, several factors need to be taken into account.

First, GC rates are seen as reflecting the price of liquidity, and their deviation from monetary policy-controlled rates might at least pose communication issues. We found that in fact GC rates might still embed general preferences about country-specific collateral and different response to excess liquidity. GC rates behave like the upper envelope of all SC rates (see Section 2.2) because in a GC transaction, a rational agent will always deliver the collateral that has the lowest value in the SC market. Thus, when specialness is extremely prevalent, GC rates cannot be considered as pure risk-free rates. A direct implication is on the monetary policy pass-through to money market rates. An increase of the DFR may not necessarily be transmitted one-for-one to repo rates. In a sense, the deviation between market rate and the policy rate signals a potential trade-off between steering short interest rates and being able to control long term yields (via assets purchase programs).

Second, repo rates have implications for bond yields. Empirical works by Jordan and Jordan (1997), Fontaine and Garcia (2012), and D'Amico et al. (2018) confirm this rela-

Table 9
Effect of PSPP purchases on SC repo rates–robustness tests. This table shows the impact of the ratio of the nominal amount bought to the total outstanding on "Spot-next" SC repo rates. We change the size of the sample to investigate if our results are robust. The first and second column are without the first quarter and the first semester of 2015. The third and the fourth columns are run with the outliers and linkers. The PSPP variable is the first difference in the share of the bond outstanding held by the PSPP.

	(1) SC repo rate	(2) SC repo rate	(3) SC repo rate	(4) SC repo rate
PSPP	−0.755***	−0.749***	−0.757***	−0.896***
	(0.0961)	(0.103)	(0.0948)	(0.113)
Bond FE	Yes	Yes	Yes	Yes
Country-bucket-time FE	Yes	Yes	Yes	Yes
R^2	0.532	0.574	0.796	0.513
Observations	168,936	117,194	208,574	186,617

Standard errors are in parentheses, clustered at the maturity-country level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

tion in the case of US Treasury market. This suggests that central bank purchases may affect bond yields through through the repo market. The existence of a relation between repo rates and bond yields may also affect the transmission of monetary policy rate to the yield curve. It may reduce the monetary policy pass-through. This occurs not only at the short end of the yield curve but also at the long end as long as scarcity prevails. For instance, Pelizzon et al. (2018) also show how scarcity distorts the price of other types of instruments such as futures contracts.

Third, specialness reflects the presence of market frictions, namely a demand for specific bonds (a form of imperfect substitutability) and imperfect arbitrage. To the extent that the PSPP reinforces bond scarcity, it means that it imposes a greater cost on those who need to borrow them. For instance, if banks borrow the bonds to fulfill their regulatory obligations (or are not allowed to lend them out), they forgo the difference between the repo rate and the DFR. The distributional effects of these costs and their impact on welfare remains unclear but would be an interesting venue for further research.

6.2. What can central banks do about the low level of repo rates?

The previous section has identified possible problems associated with the current level of repo rates. Central banks have instruments, if needed, to offset each of them.

In principle, a purely liquidity-driven rate should not trade below the DFR. Market participants should always prefer to deposit their cash into an account with the safest counterparty (the central bank). However, because some market participants do not have access to the central bank, imperfect competition and lack of arbitrage in the money market may result in rates below the DFR. If this is the case, central banks may adjust their operational framework to include instruments accessible to nonbanks, as was done in the US with an overnight reverse repo facility that is open to mutual funds, for instance (Frost et al., 2015). Alternatively, we suggest that some country-specific GC rates are currently not completely liquidity-driven when all bonds from a given country trade on special. In that case, GC rates may simply reflect the lowest SC rates of specific bonds that are relatively less in demand in the SC repo market.

This suggests that besides liquidity management, frictions associated with bond scarcity could be alleviated by the central bank to improve the monetary policy transmission. The theoretical literature supports the idea of lending bonds acquired by the central bank through a securities lending facility. Fig. 7 represents the impact of the introduction of the Security Lending Facility (SLF) in the SC repo market of a given security when such a SLF offers bonds for a minimum spread against GC (here, 10 bps).

Our empirical results suggest that the period of implementation of the SLF against cash was associated with lower pressure on the special repo market in spite of its limited size. This is likely to be the case thanks to the more attractive pricing of the SLF against cash facility (see Table 2). In countries where all bonds have value in the SC repo market, borrowing bonds against cash is also more advantageous than borrowing a scarce bond using another scarce bond.

There are therefore arguments supporting a larger securities lending facility. In theory specialness remains only because some agents are not willing to lend out the securities they hold. So far, euro area national central banks manage their securities lending on a decentralized basis. Each national central bank has different conventions with some of them being much penalizing than others.

In the US, specialness has been much less prevalent (Fleming et al., 2010; D'Amico et al., 2018). One reason for this might be related to the attractive pricing of securities lending programs of the New York Fed. The overnight SLF offers specific securities against any GC at a fee as low as 4.9 bps.[42]. In contrast, some central banks of the Eurosystem lend specific securities way below market rate (i.e. on more expensive terms), as described in Table 2.

[42] Michael Fleming, Frank Keane, Jake Schurmeier, and Emma Weiss, "A closer look at the Federal Reserves Securities Lending Program," Federal Reserve Bank of New York Liberty Street Economics (blog), August 17, 2016: http://libertystreeteconomics.newyorkfed.org/2016/08/a-closer-look-at-the-federal-reserves-securities-lending-program.html.

7. Conclusion

This paper demonstrates the links between the Eurosystem PSPP and the low level of repo rates in the euro area since 2015. We found the PSPP contributes to depressing repo rates both by increasing the scarcity of the bonds purchased and through more aggregated effects by increasing the amount of excess liquidity. Increased dispersion of repo rates below the central bank remuneration of reserves might be challenging going forward. Not only the control over short-term interbank rates may be more difficult, but it also raises the question of the transmission of monetary policy to bond yields and asset prices. Central banks, however, have instruments that could be used to mitigate such kind of distortions. Finally, our study sheds light on the possibility that central bank purchases are accommodated by short-sales and covered in the repo market in the first place, contributing to a better understanding of the mechanisms behind asset purchase programs.

Appendix A. Regulation and the repo market

Regulations of financial institutions and financial markets may impact the repo market in many ways: by incentivizing financial institutions and other market participants to hold "safe assets on balance sheets, by limiting collateral reuse and by restricting or penalizing repo leverage. In the following sections, we detail some of these regulations and their likely impact on the repo market functioning.

A.1. Regulatory demand of high-quality liquid assets

Some regulatory constraints incentivize financial intermediaries to hold bonds of the highest quality (in terms of credit and liquidity) and thus might prevent them from lending these bonds out on the repo market.

- The liquidity coverage ratio (LCR), which is part of the Basel III regulations, forces banks to hold high-quality liquid assets (HQLAs), mostly government bonds. Its phasing in started in 2015, and it will become fully effective in 2019. As of December 2016, the stock of HQLA assets held by European banks already equals 139.5% of LCR requirements. At the same date, about 2.5 trillion euro of assets are classified as HQLAs, so as of December 2016, banks are required to hold around 1.8 trillion euro of HQLAs under the LCR. Collateral borrowed in a reverse repo transaction is counted in the stock of HQLA assets of a bank if it is eligible as such. But as underlined in Klee et al. (2016), borrowing a HQLA asset via a reverse repo does not change the LCR ratio: treatment of collateral in case of repo transactions for LCR purposes implies that lending in the repo market (in which the underlying collateral is in the HQLA category) has no effect on a bank's LCR. Overall, the marginal effect of the LCR implementation is expected not to be material on repo rates in the US. The consequence of LCR ratios enforcement on HQLA assets expected returns in the US is studied in Duffie and Krishnamurthy (2016). Fuhrer et al. (2017) find that for the Swiss securities market, qualifying as a HQLA asset decreases, on average, the yield of a security by around 4 bps.
- The mandatory posting of collateral to fund initial margins (IMs) and variation margins (VMs) of OTC derivatives positions, as prescribed in the European Market Infrastructure Regulation (EMIR), might also play a role. Such requirements entered into force in 2014. Margins collected by the Central Clearing Counterparties (CCPs) are subject to haircuts, which increase with their risk.[43] Participants are likely to post as margins their highest quality holdings, which will end up on the balance sheets of CCPs. While they are allowed to reuse IMs and VMs under certain conditions, in practice it is limited. Such assets are more likely to remain on their balance sheets.

A.2. A limit on the reuse of repo collateral

'Reuse' is the activity performed on the repo market whereby agents having borrowed a security will lend it again. Reuse thus increases the supply of collateral on the repo market. Mutual funds usually reuse the collateral they receive in the course of their securities lending and derivatives positions (the collateral mitigates the counterparty risk from those operations). The UCITS[44] V regulation of mutual funds, which was enforced in March 2016, restricts the way they can reuse the collateral they receive. Reuse is permitted only if a collateral asset of at least the same quality is borrowed in exchange. Such a regulation is thus likely to decrease supply of collateral on the repo market.

A.3. Restrictions or costs on repo leverage

Other regulations impose a restriction or a cost on fleverage, which can deter financial institutions from trading repo because repo transactions increase bank's balance sheets.

- The new Money Market Funds regulation,[45] which was first drafted by the European Commission in November 2013, was ratified in April 2017 by the European Parliament. It creates pressures on the demand for short-term assets to meet daily and weekly liquidity criteria. It also imposes restrictions in the use of repurchase agreements, as money market funds (which encompass UCITS as well as AIFs[46]) can only invest in repos up to a limit of 10% of their assets.
- The leverage ratio (LR) imposes capital requirements primarily based on the size, not on the risk exposure of banks balance sheets. Under the LR, banks must have a minimum leverage ratio of 3% (that minimum starts to kick in only in 2018, but since banks have to publish their leverage ratio since 2015, the 3% threshold has become a market reference). The impact of the LR on

[43] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32012R0648&from=EN.

[44] UCITS stands for "Undertakings for collective investment in transferable securities".

[45] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1131&from=EN.

[46] AIFs stand for alternative investment funds.

the repo market is shown in CGFS (2017):"repos lead to an expansion of banks balance sheet, and therefore attract a capital charge for the intermediary under the leverage ratio. Banks can hence be expected to adjust prices or limit supply in response to this cost. To comply with the LR, we expect banks to scale down both repos and repo trades intermediation activities. Repo trades can still be netted, which removes them from the scope of the LR (Fernandez, 2017). The impact of the LR on banks repo operations has already been shown in Baklanova et al. (2016) for US and UK markets. They find that the reduction in repo activity for dealers is stronger for safer collateral than for riskier collateral. For the euro area, CGFS (2017) stresses that "activities with low risk weights are more likely to be affected by balance sheet constraints than by risk-weighted capital requirements.

A.4. Window dressing around reporting dates

In Europe, compliance with regulation is, most of the time, binding at specific dates, mainly month-ends, quarter-ends, or year-ends. For instance, the LCR ratio has to be reported at month-ends, while under the LR, European banks must report balance sheets at quarter-ends. This can entice financial institutions to do some form of window dressing around reporting dates (see, for instance, Munyan, 2015; Duffie and Krishnamurthy, 2016; Klee et al., 2016). This would be consistent with end-of-quarters volatility that we observe in the repo market. Spies and Sian (2017) underline that "banks have to report LCR ratios on a monthly basis which leads to heightened volatility in repo markets during the last days before a reporting date. They observe in US money market funds data changes in volumes at quarter-ends, noting for European banks "clear seasonality at end-quarter, as banks activity as repo counterparty fell dramatically. CGFS (2017) states that in jurisdictions where banks reporting occurs at quarter-ends, there are "incentives for banks to contract their repo exposure on these dates, giving rise to short-lived but sharp spikes in repo volumes and prices. On year-ends, additional balance sheet constraints add to the more frequent requirements. A prominent example is the contribution of banks to the Single Resolution Fund (SRF). Each year, the contribution is calculated based on the size of banks deposits.

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