Safe asset shortage and collateral re-use*

Stephan Jank[1], Emanuel Moench[2] and Michael Schneider[3]

November 19, 2020

Abstract

The re-use of collateral can support the efficient allocation of assets in the financial system. Exploiting a novel proprietary data set, we quantify banks' collateral re-use at the security level. We show that banks substantially increase their re-use of collateral in response to scarcity induced by the Eurosystem's asset purchases. Repo rates are less sensitive to purchase-induced scarcity at low levels of re-use when the banking system can more easily supply additional collateral. Elevated re-use rates, in turn, are associated with increased volatility of repo rates.

Keywords: safe assets, government bonds, collateral re-use, rehypothecation, repo market, securities lending

JEL: E4, E5, G1, G2

*We thank Darrell Duffie, Heiko Hofer, Sebastian Infante, Toomas Laaris, Julien Mazzacurati, Jose-Louis Peydro, Angelo Ranaldo, and Kathi Schlepper for helpful comments and suggestions. This paper represents the authors' personal opinions and does not necessarily reflect the views of the Deutsche Bundesbank, its staff, or the Eurosystem.

[1]Deutsche Bundesbank. Contact: Deutsche Bundesbank Research Centre, Wilhelm-Epstein-Str. 14, 60431 Frankfurt am Main, Germany. Phone: +49-69-9566-2854, E-mail: stephan.jank@bundesbank.de

[2]Deutsche Bundesbank, Goethe University Frankfurt and CEPR. Contact: Deutsche Bundesbank, Research Centre, Wilhelm-Epstein-Str. 14, 60431 Frankfurt am Main, Germany. Phone: +49-69-9566-2312, E-mail: emanuel.moench@bundesbank.de

[3]Deutsche Bundesbank and SAFE – Goethe University Frankfurt. Contact: Deutsche Bundesbank, Research Centre, Wilhelm-Epstein-Str. 14, 60431 Frankfurt am Main, Germany. Phone: +49-69-9566-3592, E-mail: michael.schneider@bundesbank.de

1 Introduction

Safe assets play an important role in the economy: they store value over time and serve as collateral in financial transactions. Increasing imbalances in the supply and demand of high-quality assets have raised concerns about a shortage of safe assets, primarily as a growing global demand for safe assets has been facing a declining pool of safe issuer countries in recent years. Furthermore, with neglected risks of securitization materializing in the financial crisis, the private production of safe assets has declined substantially. Yet, the availability of safe assets as collateral does not only depend on the issued volume. Market participants can also adjust to a shortage of safe assets by reusing received collateral in other transactions. We use a unique proprietary dataset to study this largely ignored "collateral re-use channel" in the context of safe asset scarcity induced by central bank asset purchases.

When market participants receive a security as collateral in one transaction, they can re-use it to support another transaction with a different counterparty. For example, they can use the security to raise cash in a repurchase agreement or earn a fee in a securities lending transaction. The collateral receiver, in turn, can re-use the security in a different transaction, for example in a short-sale or as collateral in another repurchase agreement. The number of times a piece of collateral is re-used in unrelated transactions is referred to as "collateral velocity". Conceptually, the collateral velocity resembles the well-known money multiplier. As collateral can be re-used multiple times, even a modest increase in collateral re-use would contribute to a significant increase in collateral available for market transactions. The more often a security is re-used as collateral, the higher the volume of financial transactions it is backing. In theory collateral velocity can be infinite, but in practice it is constrained by haircuts (Bottazzi, Luque and Pascoa, 2012) or other institutional constraints (Gorton, Laarits and Metrick, 2018). Although collateral re-use increases collateral availability, it may also raise various risks for financial stability, including the build-up of excessive leverage, growing interconnectedness, and the amplification of shocks (Brumm, Kubler, Grill and Schmedders, 2018; FSB, 2017*b*).

The failure of MF Global, a large U.S. broker-dealer, provides a prime example for the relevance of collateral re-use for market functioning. Taking advantage of differential re-hypothecation limits in the UK versus the US, MF Global extensively re-used customers' assets as collateral to finance its own transactions via its UK subsidiary. As a result, clients' assets were largely locked up after MF Global's bankruptcy on October 31, 2011, and market volatility as measured by the VIX index jumped by about 30 percent the next day.[1]

Anecdotal evidence suggests that re-use of collateral is a wide-spread practice in the financial system. However, due to a lack of data little is known about the extent to which collateral is re-used by financial intermediaries. Several studies rely on dealers' annual reports (Singh and Aitken, 2010; Singh, 2011) for information on their re-use of collateral. More recently, Infante, Press and Strauss (2018) and Infante and Saravay (2020) quantify dealers' collateral re-use in U.S. Treasuries from confidential supervisory data. However, detailed information on how dealers re-use specific bonds as collateral has not been available thus far. We fill this gap by using a regulatory data set that provides comprehensive *security-by-security* information on dealers' re-use of collateral. Specifically, we exploit a unique feature of the Bundesbank's Securities Holdings Statistics (SHS), which not only provides security-level information on German banks' portfolio holdings, but also on the amount of collateral received and posted in securities lending or repo transactions for each security. This allows us to quantify dealers' collateral re-use activity in each security. To the best of our knowledge our paper is the first to quantify collateral re-use at the security level.

We use central banks' purchases of government bonds as a laboratory to study the effects of safe asset scarcity on collateral re-use. The Eurosystem's public sector purchase

[1] McCrum, Dan (March 23, 2012) Making assets safe as houses, almost: The shock of MF Global has raised scrutiny of custody arrangements, Financial Times.

program (PSPP) imply a significant reduction of collateral available to market participants in our sample period. While the overall purchase amounts for different asset classes are published by the Eurosystem, the specific purchase amounts of individual securities are unknown in advance to market participants. We study how this reduction in available collateral affects dealers' re-use activity.

We find that dealers' aggregate re-use rate of Euro area sovereign collateral is high, fluctuating between 48.9% and 88.5% during our sample period which covers the years 2008 through 2017. The amount of collateral re-used is also substantial with regard to the outright ownership in these bonds. Before the start of the PSPP in March 2015 the amount of collateral reused was about one and a half times as large as dealers' holdings in these bonds. After the start of the PSPP this ratio increased to more than 4.5.

Using security-level information on PSPP purchases of European government bonds, we analyze how dealers adjust collateral re-use in response to a reduced availability of safe assets. We document a sizable adjustment in re-use when collateral becomes more scarce: an asset purchase of one percent of the bond's outstanding amount increases the collateral re-use in that bond by 0.21% in the same month. This increase is driven by two channels. On the one hand dealers increase the rate at which they re-use collateral that they already have available by 1.1 percentage points in response to a purchase of one percent of the bond's outstanding amount. On the other hand dealers obtain 0.15% more collateral for re-use from other market participants given the same reduction in collateral supply via the PSPP.

To what degree does this collateral re-use mitigate safe asset scarcity? To analyze this question we study the security-level re-use of German federal government bonds (Bunds) which is the collateral most commonly used by German dealer banks. Focusing on the period before the Eurosystem's enhanced securities lending facility, an asset purchase of 1% of the amount outstanding reduces bond's repo rate by 1.39 basis points. We show that dealers' ability to mitigate Bund scarcity by raising collateral re-use depends crucially on the prevailing level of collateral re-use in a bond. A one standard deviation increase in re-use increases the sensitivity of the repo rate to asset purchases by one basis point, corresponding to a relative increase by about two thirds. These results highlight the importance of collateral re-use in compensating asset scarcity. Repo rates are less sensitive to scarcity induced by asset purchases at low levels of re-use, and more so when re-use activity is already high.

A potential side effect of high collateral re-use could be an increase in the interconnectedness among market participants, which in turn might contribute to an amplification of shocks in the financial system (FSB, 2017*b*). To empirically assess the importance of this channel, we study the relation between re-use and the volatility of repo rates. Controlling for different demand and supply factors in the repo market, we find that for re-use rates above 80%, repo market volatility increases by 6-9% in the next month.

Our paper relates to several strands of the literature. First and foremost, we contribute to the literature on safe asset shortage and its consequences for the economy (e.g., Krishnamurthy and Vissing-Jorgensen, 2012; Gorton, Lewellen and Metrick, 2012; Gorton, 2017). Increasing global demand for high-quality assets has raised concerns about a shortage of safe assets. Post-crisis regulatory reforms have further raised the demand for high-quality collateral (Fender and Lewrick, 2013; Duffie, Scheicher and Vuillemey, 2015). Different solutions for alleviating safe asset scarcity have been proposed in the literature. On the one hand, the public sector can expand the production of safe assets by issuing more government debt (Gorton and Ordoñez, 2014; Brunnermeier et al., 2016). On the other hand, the financial sector can produce safe assets through securitization, but Gorton and Metrick (2012) and Gennaioli, Shleifer and Vishny (2012) highlight neglected risks in the securitization process. We document that market participants can significantly alleviate safe asset scarcity via a third channel: the re-use of received collateral. We show that this channel plays a quantitatively important role in the effective supply of available collateral to market participants and helps explain scarcity premia in the repo market.

There is a growing theoretical literature on the role of collateral re-use in financial markets. In general, this literature acknowledges a trade-off between economic efficiency and financial stability with respect to collateral re-use (Lee, 2017; Brumm et al., 2018). Bottazzi et al. (2012) show that constraints on the rehypothecation of assets induce liquidity premia in repo markets and study the conditions under which a repo market equilibrium exists. In Andolfatto, Martin and Zhang (2017) re-use of collateral improves the efficient allocation of liquidity. In Brumm et al. (2018) moderate collateral re-use improves welfare due to more efficient risk sharing, but excessive re-use increases leverage and volatility in the economy, reducing welfare. Infante (2015) highlights that runs may arise due to collateral re-use.

Empirical work on collateral re-use or rehypothecation is limited due to a lack of data. To quantify the magnitude of re-use researchers have resorted to dealers' annual reports (Singh and Aitken, 2010; Singh, 2011; Kirk, McAndrews, Sastry and Weed, 2014). More recently, Infante, Press and Saravay (2020) and Infante and Saravay (2020) quantify dealer-level collateral re-use activity from U.S. confidential supervisory data. Consistent with our findings, Infante and Saravay (2020) show that Treasury re-use increases as the supply of available securities declines through Federal Reserve asset purchases. Additionally, they document that re-use rises when profits from intermediating cash are high and that re-use sharply dropped during the market turmoil triggered by COVID-19. Our dealer-security analysis study complements these findings, allowing us to study the compensating effect of re-use on asset scarcity as well as its role with regard to repo rate volatility. Fuhrer, Guggenheim and Schumacher (2016) construct a measure of collateral re-use in the Swiss repo market from transaction data, showing that collateral re-use decreases with the availability of collateral.[2] Our data set captures the re-use of collateral not only in the

[2] Fuhrer et al. (2016) propose an algorithm to quantify collateral re-use from repo transaction data. Applying their method to the Swiss franc repo market, they find that around 5% of the interbank market was secured with re-used collateral. This is a rather low level of re-use compared to the estimates from dealers' annual reports (70-80%). The low estimate for re-use is likely due to the fact that the authors only consider repos denominated in Swiss francs and also cannot factor in securities lending transactions.

repo but also in the securities lending market, which represents an important part of the collateral intermediation chain. In the context of collateral transformation, Aggarwal, Bai and Laeven (2018) highlight the importance of the securities lending market for accessing safe assets during periods of market stress. Ferrari, Guagliano and Mazzacurati (2017) propose broker-to-broker activity in the securities lending market as a proxy for collateral re-use activities and document that it is negatively related to bonds' specialness premium, suggesting an endogenous market reaction to scarcity. This is consistent with our finding that re-use increases in response to a reduction of available high-quality collateral, and that scarcity premia are lower for securities with a higher level of re-use.

Finally, we contribute to the literature on repo markets and bond specialness (e.g. Jordan and Jordan, 1997; Krishnamurthy, 2002). Several papers study the scarcity effects of central banks' asset purchase programs on the repo market. D'Amico, Fan and Kitsul (2018) document scarcity on the repo market arising from quantitative easing in the U.S.; Corradin and Maddaloni (2017), Arrata, Nguyen, Rahmouni-Rousseau and Vari (2020), Brand, Ferrante and Hubert (2019) and Jank and Moench (2018) show similar effects for the securities markets program (SMP) and the public sector purchase program (PSPP) in the euro area. Our results highlight that the endogenous response of dealers in using scarce collateral more effectively strongly reduces the impact of such purchases on repo market specialness.

The remainder of this paper is organized as follows. Section 2 provides the institutional background for understanding the re-use of collateral by German dealer banks. Section 3 discusses the data used in our analysis. We present the main regression analysis showing that re-use responds to changes in security-specific supply in Section 4. Section 5 then documents that this reaction mitigates the effect of supply changes on repo market scarcity premia. Section 6 shows that re-use also impacts repo market volatility. Section 7 concludes.

2 Institutional background

2.1 The Eurosystem's public sector purchase program

We use the Eurosystem's public sector purchase program (PSPP) as a laboratory to study the effects of safe asset scarcity on dealers' collateral re-use activities. The PSPP was announced on 22 January 2015 and consists of the large-scale purchase of bonds issued by euro-area governments, agencies and European institutions. The program started on 9 March 2015 and is restricted to purchases in the secondary market. The majority of securities bought under the program are acquired by the national central banks. The geographic allocation of PSPP purchases closely tracks the national central banks' subscription to the ECB capital key. By the end of our sample period in December 2017, total PSPP purchases reached almost €1.9 Tn.[3] In our analysis, we make use of proprietary security-level information on Eurosystem PSPP purchases.

To reduce potential scarcity effects on the repo market the Eurosystem initiated a securities lending program which started shortly after the PSPP on 2 April 2015. Over the course of the PSPP, the Eurosystem made its holdings available for securities lending though various channels. Initially, securities lending was carried out as combined repo/reverse repo transactions. Specifically, if a bank wished to borrow a specific government bond, it had to offer an equivalent bond as collateral. For example, if a bank intended to borrow a specific German government bond, it had to provide another German government bond as collateral. In December 2016 the ECB enhanced the securities lending facilities in several ways. The overall limit was raised, and, most notably, it became possible to borrow securities via a repo transaction without an offsetting reverse repo, i.e. against cash collateral.[4] Whereas previously purchases led to a reduction in the supply of collateral, this was less the case after the enhancement. Arrata et al. (2020), Brand et al. (2019) and Jank and Moench (2018) all document that the subsequent period of the Eurosystem

[3]See https://www.ecb.europa.eu/mopo/implement/omt/html/index.en.html

[4]https://www.ecb.europa.eu/press/pr/date/2016/html/pr161208_2.en.html

enhanced securities lending facility is associated with lower pressure of Eurosystem asset purchases on the special repo market.

2.2 Definition of collateral re-use

Following the broad definition of the FSB (2017*b*), collateral re-use includes "any use of assets delivered as collateral in a transaction by an intermediary or other collateral taker". Market participants receive securities as collateral from various transactions, such as reverse repos, securities lending, margin lending, and over-the-counter derivative transactions. If the collateral received is eligible for re-use, the financial institution can re-use the security to support another transaction. The definition of collateral re-use is more general than the narrower concept of collateral re-hypothecation, which refers to the use of client's assets (FSB, 2017*b*) as collateral.

We study financial institutions' received and posted collateral from securities financing transactions, which include reverse repo transactions and securities lending. Importantly, collateral received from these transactions is eligible for re-use since securities lending and repo transactions in Europe typically involve full temporary transfer of title of the underlying security. Data collected by the ESRB suggest that a large proportion of collateral re-use is currently occurring via securities financing transactions (Keller et al., 2014). Specifically, the study reports that for European banks 98% and 99% of collateral received through reverse repo and securities lending/borrowing transactions are eligible for re-use, respectively.

3 Data and descriptive statistics

3.1 Measuring re-use of collateral

Our analysis relies on the Bundesbank's Securities Holdings Statistics (SHS) which provides isin-by-isin data on German banks' security portfolios at quarter and – since 2013 – month ends. In addition to the banks' own holdings, the data also include for each security the amount of collateral received and posted arising from securities lending and repo transactions. Due to their conceptual similarity, securities lending transactions and repos are pooled in the securities holdings statistics. The original purpose of collecting figures on collateral received and posted is to avoid double counting in securities holdings. We utilize this information to compute security-specific re-use activity at the bank level.[5] As securities lending and repo transactions in Europe typically involve full temporary transfer of title of the underlying security, all received collateral in the SHS is eligible for re-use.

We focus on sovereign bonds issued by Euro-area countries with a remaining maturity between 1 and 30 years and denominated in Euro. Furthermore we require an investment grade rating (BBB or higher) and restrict our analysis to countries for which BrokerTec provides repo rate information.[6] Before calculating our re-use measures we apply the following filters to the data. A security may also be obtained through securities lending or a reverse repo with the purpose of creating a short position. To separate short selling from collateral re-use activity we filter out all negative positions before proceeding. We further employ a plausibility check to our data by checking whether collateral posted exceeds the sum of amount owned outright and collateral received. If this inequality is violated we omit the erroneous position. Moreover, we restrict the sample to bonds that are actively used by German dealers as collateral. To this end we drop observations where the collateral posted is zero both for the current and the previous period.

Figure 1(a) describes the dynamics of the aggregate collateral received and posted, normalized by the outright ownership across dealers and securities. Both metrics move in lockstep, already suggesting that much of the received collateral is re-used when collateral is posted. Moreover, the figure shows that both collateral received and posted are consistently above one, i.e. both exceed the dealers' outright holdings. While both metrics range

[5] The data, however, does not contain any information on haircuts.

[6] The BrokerTec data covers all major Euro-area sovereign debt markets. Specifically, our analysis includes sovereign bonds issued by Austria, Belgium, Germany, Spain, Finland, France, Greece, Ireland, Italy, Netherlands, and Portugal.

between one and three from the beginning of our sample in 2007 until 2015, they increase to considerably higher levels after the introduction of the PSPP.

Using the dealers' own holdings as well as their collateral received and posted allows us to quantify their collateral re-use activity in each security. Our main measure follows the FSB's (2017*a*) final recommendation for measuring re-use:

$$\textit{Re-use}_{ij} = \left(\frac{\textit{Collateral received}_{ij}}{\textit{Collateral received}_{ij} + \textit{Outright ownership}_{ij}} \right) \times \textit{Collateral posted}_{ij}, \tag{1}$$

where $\textit{Collateral received}_{ij}$ $(\textit{Collateral posted}_{ij})$ is the market value of bond i received (posted) as collateral by dealer j, and $\textit{Outright ownership}_{ij}$ is the market value of dealer j's outright ownership of bond i. The measure assumes proportional use of own assets and collateral received when posting collateral. This is in line with the responses received by market participants to a call for evidence by the FSB. In general it is common practice for market participants to not distinguish between own securities or securities originating from another collateralized transaction when posting collateral (FSB, 2017*a*).

Figure 1(a) also shows the aggregate amount of collateral re-used, normalized by the outright ownership. The ratio is always slightly lower than for collateral posted or received. It closely tracks the other two metrics, including the sharp increase during the PSPP period.

We compute dealer j's re-use rate in bond i as follows:

$$\textit{re-use rate}_{i,j} = \left(\frac{\textit{Re-use}_{i,j}}{\textit{Collateral received}_{i,j}} \right). \tag{2}$$

When there is no collateral received we define $\textit{re-use rate}_{i,j} \coloneqq 0$. The re-use rate measures the fraction of collateral received that has been re-used by a dealer bank. It is is an indicator how extensively the dealer uses its collateral resources and therefore sometimes referred to as "collateral efficiency" (Kirk et al., 2014). We also compute a security-specific re-use rate $\textit{re-use rate}_i$ by aggregating for a specific bond i the amount of collateral re-used and received over all German dealers.

Figure 1(b) shows the aggregate re-use rate over time. Consistent with anecdotal evidence, collateral re-use declined in times of market tress such as the global financial crisis of 2007-2008 and the European sovereign debt crisis. Moreover, there appears to be a further decline in the re-use rate around 2015, coinciding with the Basel III leverage ratio disclosure requirement. After the start of the Eurosystem's public sector purchase program (PSPP) in 2015 re-use activity has been continuously on the rise.

For robustness we compute two alternative measures which represent an upper and lower bound for the proportional measure of collateral re-use activity, respectively. As an upper bound to the amount of collateral re-used we define (FSB, 2016):

$$\textit{Collateral re-used}_{ij}^{upper} = \min(\textit{Collateral received}_{ij}, \textit{Collateral posted}_{ij}). \tag{3}$$

This measure assumes that a dealer first uses all the collateral received of a particular bond before resorting to its outright owned shares. Finally, the lower bound to the amount of collateral re-used is given by:

$$\textit{Collateral re-used}_{ij}^{lower} = \max((\textit{Collateral posted}_{ij} - \textit{Own assets}_{ij}), 0) \tag{4}$$

This measure assumes that a dealer first uses all its outright owned shares of a particular bond before resorting to the collateral received.

Consider the following example for illustration of the three re-use measures. Dealer A posts 90 million EUR of a specific bond as collateral. The posted collateral can in principle originate from two sources: own assets or collateral received. In our example dealer A received 100 million EUR as collateral and owns outright 20 million EUR. Hence, the lower bound of collateral re-used is given by $\max((90-20), 0) = 70$ million EUR. In this case the dealer first depletes all own holdings (20 million EUR) before using the collateral received of which she sources the remaining amount (90-20 = 70 million EUR). So, we know for sure that the dealer re-uses 70 million EUR of its received collateral. The proportional measure of collateral re-use is given by $(100/(100+20)) \times 90 = 75$ million EUR. Here the dealer obtains collateral proportionally from the two sources, of which collateral received accounts to $100/(100+20) = 83.3\%$. The upper bound of collateral re-use is given by $\min(100, 90) = 90$ million EUR. Here the dealer fully sources her posted collateral with collateral received. Relating the amount of collateral re-used to the amount of collateral received (100 million EUR), the corresponding re-use rates for the lower bound, proportional approach, and upper bound are 70%, 75% and 90%.

Note that the three measures specified in equations (1), (3) and (4) are identical if the dealer has no outright ownership in a particular bond. In this case all the posted collateral has to come from collateral received. Following the same logic, if the outright ownership becomes small relative to collateral posted and received the three measures converge. Indeed, we find that the three measures yield very similar re-use rates in our sample.[7] In what follows, we will thus focus on the proportional measure of collateral re-use since it most closely resembles actual market practices. As a robustness check we repeat our main analyses in the Internet appendix using the upper/lower bound approach, and obtain very similar results.[8]

3.2 Descriptive statistics

Figure 2 shows the aggregate market value of collateral re-used over time, where we distinguish between domestic (i.e. German) sovereign bonds and bonds issued by other Euro-area countries. The aggregate value of re-used collateral was highest at the beginning of our sample in 2007 at more than 60 billion EUR and decreased to less than 20 billion EUR in early 2014. Re-use volume picked up again towards the end of 2015 and was at

[7]See Table IA.1. The correlation of the re-use rate obtained using the proportional measure with the re-use rate from both the upper and lower bound is very high at 0.97. The upper and lower measure also have a correlation of 0.90.

[8]See Table IA.2 of the Internet Appendix

around 50 billion EUR during 2017. The share of domestic collateral with respect to the total Euro denominated Euro area member country sovereign collateral is roughly constant over time at, ranging between 31.3% and 64.4%. In Figure 3 we report the average share of collateral re-used by issuer country and rating, respectively. German bonds, on average, account for 43.1% of market value, while Italian and French bonds represent 18.1% and 13.4% of the total, respectively. Austrian and Dutch bonds take up 6.1%, each, and Belgian bonds are 5.1%. In terms of ratings, the vast majority (63.1%) of re-used collateral is AAA-rated and 22.9% has a AA rating. 14.0% are rated either A or BBB.

4 Collateral re-use adjustment to scarcity of safe assets

In this section, we empirically analyze how dealers react to changes in collateral scarcity. We first look at the overall scarcity-induced adjustment in collateral re-use. We then decompose this adjustment into changes in the re-use rate of available collateral and changes in the amount of collateral available for re-use.

4.1 Overall Re-Use Response to Scarcity

We first investigate how market participants adjust the effective usage of collateral to a shock in collateral supply. We use the Eurosystem's large-scale purchases of government bonds via its Public Sector Purchase Program (PSPP) as our measure of exogenous variation in safe asset shortage on the repo market. Our approach resembles that of the literature which studies the effects of central banks' asset purchases on bond yields (Schlepper, Hofer, Riordan and Schrimpf, 2018; De Santis and Holm-Hadulla, 2017) or on bond specialness (D'Amico et al., 2018; Arrata et al., 2020; Corradin and Maddaloni, 2017). Our basic panel regression specification is the following:

$$\begin{aligned} \Delta \log(\textit{re-use})_{i,j,t} &= \beta_0 + \beta_1 \textit{Purchase}_{i,t} + \gamma' \text{Controls}_{i,t} \\ &\quad + \alpha_{j,t} + \alpha_{i,j} + \alpha_{m,c,t} + \varepsilon_{i,j,t}, \end{aligned} \tag{5}$$

where $\Delta \log(\textit{re-use})_{i,j,t}$ is the change in collateral re-use over month t of dealer j. The main explanatory variable of interest is $Purchase_{i,t}$, the amount of bond i that is purchased in the same month by the Eurosystem, measured in percent of the total amount outstanding. If market participants expand their collateral re-use in response to a tightening of supply, we expect a positive sign for the coefficient β_1.

Equation (5) represents our most saturated regression model, including various high-dimensional fixed effects. $\alpha_{j,t}$ denotes dealer×time fixed effects, which absorb any regulatory shocks to the dealers or any other observable or unobservable shocks to dealers that may affect their willingness to re-use collateral (e.g., funding or liquidity shocks). Including dealer-time fixed effects is important, because the sample period we consider (2015-2017) is not only characterized by the Eurosystem's asset purchase program, but also by a number of macroprudential policies that came into effect. In particular, Basel III regulations introduced in this period, such as the leverage ratio or liquidity coverage ratio, may affect dealers' willingness to participate in the repo market or to re-use collateral. These regulations are likely to affect dealer banks differently and possibly result in confounding effects in the previous analysis. For example, Kotidis and van Horen (2018) demonstrate that U.K. dealer banks reduced their repo intermediation as response to the introduction of the leverage ratio. Additionally, we include dealer-bond fixed effects $\alpha_{i,j}$ in the regression, which absorb any unobservable dealer-bond-specific variation, for example dealers' specialization in trading certain bonds. Following Arrata et al. (2020), we also include maturity bucket×country×time fixed effects $\alpha_{m,c,t}$ to account for effects related to the issuer (e.g. rating changes), the yield curve (e.g. haircuts) and market-wide variation. As in Arrata et al. (2020), we define maturity buckets for one to two years, two to five years, five to ten years, and ten to thirty years. Standard errors are clustered at the bond×time level.

We control for various factors that capture changes in supply or demand of collateral by including $Controls_{i,t}$. A bond's supply to the repo market increases if that particular bond reopened for auction and its total amount outstanding rose. We therefore control for changes in the amount outstanding. In the government bond market the most recently issued bond of its type ("on the run") is generally more liquid than the previously issued bond ("off-the-run") (Krishnamurthy, 2002). Since on-the-run bonds are often in high demand on the repo market (Jordan and Jordan, 1997) we control for the on-the-run status using a dummy variable. Another reason for a bond to be in high demand is when it becomes the cheapest-to-deliver in the futures market (Buraschi and Menini, 2002; Brand et al., 2019). Some investors will have difficulties buying bonds that they need for Futures delivery. To avoid penalties from a failure to deliver these investors will borrow the bond in the repo market, leading to a high demand for this bond. We therefore also control for the cheapest-to-deliver status.

Table 2 shows the results from this benchmark panel regression. Starting point is the specification in Column (1), which only includes dealer, stock, and time fixed effects. The coefficient for *Purchases* shows that there is a significant positive relationship between changes in collateral re-use and the share of a bond purchased by the PSPP. This shows that market participants react to rising collateral scarcity by increasing the re-use of collateral. This finding is robust across all specifications (2) to (5), where we subsequently include various multidimensional fixed effects. The effect even increases in economic magnitude, in our most saturated regression of column (5), including dealer-time, dealer-bond and maturity bucket-country-time fixed effects. The coefficient estimate of 0.21 indicates that a one percentage point purchase of the Eurosystem as a share of the total outstanding of a bond increases the collateral re-use by about 0.21%.

With regard to our control variables, we find that collateral re-use is positively associated with increases in the amount outstanding, which is marginally significant in specification (5). This is intuitive as more collateral becomes available for re-use through re-issuance. When bonds are in high demand, such as when they are "on the run" or "cheapest to deliver", we also see a positive albeit not statistically significant coefficient with respect to log re-use changes.

In sum, our baseline regression shows that collateral re-use by dealers increases in response to an increase in scarcity induced by central bank purchases.

4.2 Intensive and extensive margin of collateral re-use adjustment

We next study how dealers adjust their collateral re-use. On the one hand, they can increase the rate at which they re-use already received collateral. On the other hand, dealers can search for more collateral to borrow in the market in order to channel it to prospective borrowers. We refer to the former as the intensive and to the latter as the extensive margin of collateral re-use. To study the two channels we run a similar regression as described in Equation (5), but use Δ*re-use rate* and $\Delta \log(\textit{Collateral received})$ as dependent variables instead.

Table 3 reports the results of these regressions, using the most saturated fixed effect specification. Column (1) repeats the analysis of Table 2 with $\Delta log(\textit{re-use})$ as dependent variable, serving as comparison. Column (2) looks at dealers' intensive margin, i.e. how they adjust the re-use rate in response to increased collateral scarcity induced by asset purchases. We find that dealers increase their re-use rate by 1.14 percentage points in response to an asset purchase that amounts to 1% of the bond's outstanding amount. We also observe that dealers adjust at the intensive margin when a bond is in high demand in the market for collateral. They raise their re-use rate by 6.3 percentage points for on-the-run relative to off-the-run bonds.

As can be seen from Column (3) dealers are not only adjusting at the intensive but also the extensive margin of collateral re-use when a bond becomes scarce. The amount of collateral received increases by 0.15 percent for a purchase of 1% of the outstanding amount, but this effect is only statistically significant at the 10% level. Looking at our control variables, we see that when the amount outstanding of a bond rises this increases also the availability of this bond, which in turn leads to an increase in collateral received of that bond.[9]

As discussed in Section 5, the majority of re-used collateral of German dealers is domestic. In the subsequent analyses, we will focus on German Bunds only, where the banks in our sample are most active. By means of comparison, Columns (4) - (6) of Table 3 repeat our previous analysis for German government bonds only. For all three specifications, the point estimates are larger than for the overall European sample. An asset purchase of 1% of increases the level of reuse of German collateral by about 0.29 percent and the reuse rate by 1.65 percentage points. Also for German collateral there is a positive association between asset purchases and collateral received, however the coefficient is statistically insignificant with a p-value of 1.56.

4.3 Economic magnitude of the re-use collateral channel

We have shown that dealers react to scarcity-inducing purchases primarily via the intensive margin, that is by adjusting their re-use rate. To highlight the economic significance of these adjustments we perform the following exercise. Given a reduction in the supply of collateral, how much additional collateral do dealers need to provide through collateral re-use in order to maintain a constant amount of collateral in the market-place?

For a given base amount of collateral that is available, we can compute the effective amount of available collateral it is able to support[10]:

$$\begin{aligned} \textit{effective amount} &= \textit{base amount} \times (1 - HC) \times \sum_{n=0}^{\infty} (\textit{re-use rate} \times (1 - HC))^n \\ &= \textit{base amount} \times \frac{(1 - HC)}{1 - \textit{re-use rate} \times (1 - HC)}\,, \end{aligned} \tag{6}$$

[9] We also perform a robustness check regarding the different measures of collateral re-use introduced in Section 3. Our results are virtually the same when using the upper or lower bound for collateral re-use and the re-use rate as dependent variable. Result for this robustness check are shown in Table IA.2 in the Internet appendix.

[10] We thank Toomas Laarits for this suggestion.

where HC is the haircut applied to the collateral each time it is (re-)used. The intuition behind Equation (6) is the following. Suppose bank A uses a certain amount of a bond as collateral in its transaction with bank B. This collateral is sourced from its outright holdings and we refer to it as the base amount of collateral. Bank B has access to this amount minus the haircut HC and re-uses part of this collateral in another transaction with bank C. At this point the effective amount of collateral available is equal to the sum of the base amount less the haircut, the one received by bank B and the amount received by bank C. As this series of re-uses goes to infinity, it can be interpreted as a geometric sum, yielding the second identity of Equation (6) (Bottazzi et al., 2012).

Given our estimated re-use rates, what would this imply for the total collateral available? To answer this question, we calibrate Equation (6) to our data. We assume a haircut of 3% and a re-use rate of 62.7%, which is the median value in the dealer-security panel used in our previous estimation.[11] Hence, at the given values of re-use rate and haircut one unit of a bond supports 2.5 times as much collateral in the market.

Given a reduction in the supply of collateral, how do dealers need to adjust their re-use rate in order to maintain constant the effective amount of collateral? Equation (6) implies that for a reduction in the base amount by 1%, the new re-use rate in our example needs to be 63.1%, i.e. an increase by 0.4 percentage points. This is considerably lower than the estimated coefficient of in Table 3, Column (2). An asset purchase of 1% of the amount outstanding increases the re-use rate by 1.14 percentage points.[12] In other words, at first sight dealers seem to overcompensate the collateral reduction through collateral re-use.

One potential explanation for this discrepancy is that a purchase of 1 percent of the amount outstanding actually corresponds to a substantially larger depletion of the pool of collateral that can be accessed by dealers. This could be the case if central banks buy disproportionately from holders that would otherwise supply these assets as collateral.

[11] The mean (median) haircut for our sample as reported in the ECB's eligible assets database is 2% (3.3%).

[12] Our conclusion is robust at different levels of re-use and the haircut, cf. Table IA.3 in the Internet appendix.

Hence a purchase of 1 percent of the amount outstanding may actually correspond to a reduction in the effective amount of collateral available to re-use that is about three times as large. Consistent with this notion, Koijen, Koulischer, Nguyen and Yogo (2020) find that (after foreign investors) Euro-area banks, which generally supply their holdings as collateral, are the second largest net seller of Euro-area government bonds. They reduced their holdings by 470 billion EUR from the first quarter of 2015 to the last quarter of 2017, corresponding to 25% of purchases. In contrast, insurance companies and pension funds, which are generally less likely to supply collateral to the market (Duffie, 1996), increase their holdings over the same period.[13]

5 Collateral re-use and bond scarcity

We next explore how collateral re-use is related to a commonly used market measure of bond scarcity, the specialness spread. A bond is referred to trade "on special" in the repo market when the specific repo rate for that bond is lower than the general collateral rate (Duffie, 1996), e.g. due to increased demand. The specialness spread measures the cost of borrowing a specific collateral in the repo market.

Dealers can increase supply in the repo market by reusing the collateral received in other transactions. However, there is a binding constraint as dealers cannot post more collateral than they received or own (Bottazzi et al., 2012), and may additionally be restricted by haircuts or margin requirements. We therefore study how market participants' reaction to asset scarcity depends on the already reached level of collateral re-use.

In order to capture the impact of collateral re-use on bond scarcity, we require a good coverage of overall re-use activity. As shown in Figure 3, the German banks are mostly using domestic collateral in their transactions. Government bonds of other countries are

[13] Another explanation could be that re-use chains are not infinitely long. That said, if we assume that each unit of collateral is re-used only five (ten) times, i.e. if we truncate the sum in Equation (6) at $n = 5$ ($n = 10$), we still obtain a multiplier of 2.35 (2.47) in the example above. Only when we assume that collateral is re-used once or twice is the calculated estimate comparable to the empirically observed value. However we deem such short chains unlikely.

also used, but German bank market coverage is not as far reaching, which we need when we aggregate to the security level. Therefore, from here on, we focus on the re-use of German sovereign bonds. In the Internet appendix, we repeat our analysis for a larger set of Euro area bonds for which the banks of our sample are comparably active, yielding very similar results.[14]

The standard approach to compute a bond's specialness spread is to subtract from the bond's specific collateral rate a general collateral rate as a proxy for the risk-free funding rate. However, as Arrata et al. (2020) point out, the general collateral rate may be a biased benchmark when all eligible bonds are on special. We therefore follow their approach and use the specific collateral rate instead of the specialness spread to measure bond scarcity premia. The time fixed effects included in our regressions will capture any changes in the general collateral rate.

To evaluate the effect on asset scarcity we follow the regression framework of Arrata et al. (2020) and run a regression with changes in the specific collateral repo rate $\Delta \textit{repo rate}_{i,t}$ as dependent variable:

$$\begin{aligned} \Delta \textit{repo rate}_{i,t} &= \beta_0 + \beta_1 \textit{Purchase}_{i,t} + \beta_2 \log(\textit{Re-use/Outright ownership})_{i,t-1} \\ &\quad + \beta_3 \textit{Purchase}_{i,t} \times \log(\textit{Re-use/Outright ownership})_{i,t-1} \\ &\quad + \gamma' \textit{Controls}_{i,t} + \alpha_i + \alpha_{m,t} + \varepsilon_{i,t} \quad . \end{aligned} \tag{7}$$

We interact PSPP purchases $\textit{Purchase}_{i,t}$ with the lagged level of collateral re-use. The intuition is as follows: for moderate levels of collateral re-use it should be relatively straightforward for market participants to react to a reduction in collateral supply by expanding their re-use activity. For high levels of collateral re-use, on the contrary, dealers may not easily be able to compensate the reduced supply by collateral re-use, which should result in increased scarcity. We standardize collateral re-use by dividing the amount re-used

[14] Cf. Table IA.4 of the Internet Appendix.

by outright ownership and take the logarithm, i.e. log(*Re-use/Outright ownership*). As above, Controls accounts for changes in the amount issued and on-the-run and cheapest-to-deliver status. We include bond fixed effects and maturity bucket×time fixed effects. Standard errors are clustered at the bond level.

Table 4 presents the estimation results. In December 2016 the Eurosystem enhanced its securities lending program by accepting cash collateral to support repo market functioning among other things. We therefore split our sample at this date and report results for the pre-period in Columns (1) and (2), and in Columns (3) and (4) for the post-period. The pre-cash collateral period provides the clearest setting as asset purchases then reflect exogenous reductions in bond supply to the repo market. In Columns (1) and (3) we estimate the baseline regression without the interaction term. Consist with the prior literature, we find that asset purchases compress repo rates, i.e. they increase bonds' specialness. An asset purchase of 1% of the amount outstanding reduces the bond's repo rate by 1.39 basis points during the pre-Enhancement period in Column (1). Despite the fact that our estimation approach is monthly and our sample is restricted to German government bonds during a shorter period, the magnitude is similar to Arrata et al. (2020), who report a reduction of 0.78 basis points with regard to a 1% PSPP purchase. For the post-Enhancement period we estimate a slightly lower coefficient of 1.03 which is significant only at the 10% level, likely in part owing to the smaller sample size.

In Columns (2) and (4) we include the interaction term related to the past level of collateral re-use. Crucially, the interaction term for purchases and re-use in Column (2) for the pre-Enhancement period is significant, both in statistical and economic terms. A one standard deviation increase in the normalized re-use measure (2.28) increases the sensitivity of the repo rate to asset purchases by almost one basis point ($2.28 \times -0.42 = -0.96$) for each percent share of amount outstanding purchased. This corresponds to an increase by about two thirds with respect to the baseline sensitivity. On the contrary we observe no such effect for the later sample period after the Enhancement of securities lending facilities in Column (4).

These results highlight the importance of collateral re-use in compensating asset scarcity. Repo rates are less sensitive to scarcity induced by asset purchases at low levels of re-use, and more so when re-use activity is already high. Our findings also suggest that the enhancement of the securities lending facilities was effective in mitigating the scarcity effect of asset purchases on the repo market (Brand et al., 2019).

6 Collateral re-use and repo rate volatility

Market participants can also contribute to dampening scarcity effects by more efficiently using their available collateral. Collateral re-use, however, can also increase the interconnectedness among market participants and thereby amplify shocks (FSB, 2017*b*). In this section we analyze the degree to which higher re-use rates manifest themselves in higher volatility on the repo market.

We investigate this question in Figure 4, which shows a binned scatter plot of bonds' repo-market volatility and their lagged re-use rate. We subtract the average repo rate volatility of each month in order to account for large seasonal spikes in volatility (especially at year- and quarter-end). The figure clearly shows that repo market volatility is positively associated with the lagged re-use rate of a bond and that this relationship is non-linear. In particular, bonds with a very high re-use rate experience much higher repo rate volatility. This provides initial evidence that excessive re-use of collateral may be associated with high volatility in the repo market.

We study the relation of repo market volatility and collateral re-use rate more formally in the following regression framework:

$$\begin{aligned}\log(\textit{repo rate volatility})_{i,t} \;=\;& \beta_0 + \beta_1 I(\textit{re-use rate}_{i,t-1} > 80\%) + \\ & \gamma' \text{Controls}_{i,t-1} + \alpha_i + \alpha_t + \varepsilon_{i,t},\end{aligned} \tag{8}$$

where the dependent variable log(*repo rate volatility*)$_{i,t}$ is the logarithm of the realized volatility of the repo rate of bond i over the period of month t. To capture the possibly non-linear link between repo rate volatility and re-use rate our key explanatory variable of interest is a dummy variable that equals one if the lagged re-use rate is above 80% and is zero otherwise. The regression includes time fixed effects α_t, which absorb the well-documented seasonal repo market volatility patterns. The regression also includes bond fixed effects α_i. Furthermore, we control for time-varying bond characteristics that have been shown to affect the repo rate and may thus also affect its second moment. Specifically, we include dummy variables for on-the-run status and when a bond is the cheapest-to-deliver in Futures contracts. Additional controls are the lagged yield and the log of the total amount outstanding.

Table 5 reports the regression results of Equation (8), confirming the results of the scatter plot. Bonds with a high collateral re-use rate experience increased repo rate volatility in the next month. In Column (2) we include two additional controls, the overall share purchased by the PSPP and the lagged repo rate of the bond. Both variables are positively related to collateral re-use, as we have shown above that dealers expand re-use when bonds become scarce. Hence, we expect these two variables to pick up some of the effects attributed to the collateral re-use rate. Intuitively, bonds with a low repo rate, i.e. bonds that trade on special, experience higher future repo rate volatility. The overall PSPP share, on the other hand, does not predict repo rate volatility in addition to the other control variables. As expected, the coefficient for *Dummy: re-use rate high* is slightly reduced in magnitude to 0.06 with respect to the baseline, but remains statistically significant at the 5% level. In other words, a high collateral re-use rate affects repo market volatility over and above the lagged repo rate.

In Columns (3) and (4), we investigate if this result is driven by the strong year-end spikes of repo market volatility. Even when excluding year-ends, we still document a significant coefficient for high re-use rates. Point estimates for the coefficient of lagged re-use rate are even slightly larger when year-end effects are excluded. Overall, the estimates suggest that switching from a bond with low re-use rate to a bond with a high reuse rate (greater or equal to 80%), increases its repo rate volatility in the range of 6-9%.

In sum, while dealers' re-use of safe-asset collateral mitigates scarcity effects induced by central bank asset purchases, a high level of re-use is associated with more repo market volatility.

7 Conclusion

In this paper we document that dealer banks adjust to safe asset scarcity by making more efficient use of received collateral. Following an asset purchase by the Eurosystem, dealers increase their collateral re-use rate. The increase in collateral re-use absorbs part of the supply reduction, which is reflected in a lower scarcity premium on the repo market following an asset purchase. Increasing collateral re-use in the market also has a downside: high levels of collateral re-use are associated with high volatility in the repo market.

From a policy perspective our results highlight a new trade-off between unconventional monetary policy and financial stability. As a side effect to quantitative easing, asset purchases increase collateral re-use, which in turn increases volatility in the repo market. More generally, our results suggest that global supply and demand imbalances for safe assets impact financial markets beyond the high price for safe assets. Market participants' adjustment to safe assets through collateral re-use may potentially result in an amplification of shocks and increased volatility.

References

Aggarwal, R., Bai, J. and Laeven, L. (2018), 'Safe asset shortages: Evidence from the European government bond lending market', *Working Paper* .

Andolfatto, D., Martin, F. M. and Zhang, S. (2017), 'Rehypothecation and liquidity', *European Economic Review* **100**, 488–505.

Arrata, W., Nguyen, B., Rahmouni-Rousseau, I. and Vari, M. (2020), 'The scarcity effect of quantitative easing on repo rates: Evidence from the Euro area', *Journal of Financial Economics* **137**(3), 837–856.

Bottazzi, J.-M., Luque, J. and Pascoa, M. R. (2012), 'Securities market theory: Possession, repo and rehypothecation', *Journal of Economic Theory* **147**(2), 477–500.

Brand, C., Ferrante, L. and Hubert, A. (2019), 'From cash-to securities-driven Euro area repo markets: the role of financial stress and safe asset scarcity', *ECB Working Paper Series No 2232 / January 2019* .

Brumm, J., Kubler, F., Grill, M. and Schmedders, K. (2018), 'Re-use of collateral: Leverage, volatility, and welfare', *ECB Working Paper Series No 2218* .

Brunnermeier, M. K., Garicano, L., Lane, P. R., Pagano, M., Reis, R., Santos, T., Thesmar, D., Van Nieuwerburgh, S. and Vayanos, D. (2016), 'The sovereign-bank diabolic loop and ESBies', *American Economic Review* **106**(5), 508–12.

Buraschi, A. and Menini, D. (2002), 'Liquidity risk and specialness', *Journal of Financial Economics* **64**(2), 243–284.

Corradin, S. and Maddaloni, A. (2017), 'The importance of being special: repo markets during the crisis', *ECB Working Paper 2065, May 2017* .

D'Amico, S., Fan, R. and Kitsul, Y. (2018), 'The scarcity value of treasury collateral: Repo-market effects of security-specific supply and demand factors', *Journal of Financial and Quantitative Analysis* **53**(5), 2103–2129.

De Santis, R. A. and Holm-Hadulla, F. (2017), 'Flow effects of central bank asset purchases on euro area sovereign bond yields: evidence from a natural experiment'.

Duffie, D. (1996), 'Special repo rates', *The Journal of Finance* **51**(2), 493–526.

Duffie, D., Scheicher, M. and Vuillemey, G. (2015), 'Central clearing and collateral demand', *Journal of Financial Economics* **116**(2), 237–256.

Fender, I. and Lewrick, U. (2013), 'Mind the gap? sources and implications of supply-demand imbalances in collateral asset markets', *BIS Quarterly Review* **3**, 67–80.

Ferrari, M., Guagliano, C. and Mazzacurati, J. (2017), 'Collateral scarcity premia in euro area repo markets', *Working Paper* .

FSB (2016), Possible measures of non-cash collateral re-use, Report.

FSB (2017*a*), Non-cash collateral re-use: Measure and metrics, Report.

FSB (2017*b*), Re-hypothecation and collateral re-use: Potential financial stability issues, market evolution and regulatory approaches, Report.

Fuhrer, L. M., Guggenheim, B. and Schumacher, S. (2016), 'Re-use of collateral in the repo market', *Journal of Money, Credit and Banking* **48**(6), 1169–1193.

Gennaioli, N., Shleifer, A. and Vishny, R. (2012), 'Neglected risks, financial innovation, and financial fragility', *Journal of Financial Economics* **104**(3), 452–468.

Gorton, G. (2017), 'The history and economics of safe assets', *Annual Review of Economics* **9**, 547–586.

Gorton, G., Laarits, T. and Metrick, A. (2018), 'The run on repo and the Fed's response', *NBER Working Paper No. 24866* .

Gorton, G., Lewellen, S. and Metrick, A. (2012), 'The safe-asset share', *American Economic Review* **102**(3), 101–06.

Gorton, G. and Metrick, A. (2012), 'Securitized banking and the run on repo', *Journal of Financial economics* **104**(3), 425–451.

Gorton, G. and Ordoñez, G. (2014), 'Collateral crises', *American Economic Review* **104**(2), 343–378.

Infante, S. (2015), 'Liquidity windfalls: The consequences of repo rehypothecation', *Journal of Financial Economics, forthcoming* .

Infante, S., Press, C. and Saravay, Z. (2020), Understanding collateral re-use in the us financial system, *in* 'AEA Papers and Proceedings', Vol. 110, pp. 482–86.

Infante, S., Press, C. and Strauss, J. (2018), 'The ins and outs of collateral re-use', *FEDS Notes* .

Infante, S. and Saravay, Z. (2020), 'What drives us treasury re-use?', *Working Paper, Federal Reserve Board* .

Jank, S. and Moench, E. (2018), 'The impact of Eurosystem bond purchases on the repo market', *Bundesbank Research Brief, 21st edition - September 2018* .

Jordan, B. D. and Jordan, S. D. (1997), 'Special repo rates: An empirical analysis', *The Journal of Finance* **52**(5), 2051–2072.

Keller, J., Bouveret, A., Picillo, C., Liu, Z., Mazzacurati, J., Molitor, P., Söderberg, J., Theal, J., de Rossi, F. and Calleja, R. (2014), Securities financing transactions and the (re)use of collateral in Europe, Report, European Systemic Risk Board.

Kirk, A., McAndrews, J., Sastry, P. and Weed, P. (2014), 'Matching collateral supply and financing demands in dealer banks', *Economic Policy Review* (Dec), 127–151.

Koijen, R. S., Koulischer, F., Nguyen, B. and Yogo, M. (2020), 'Inspecting the mechanism of quantitative easing in the euro area', *Banque de France Working Paper No. 601* .

Kotidis, A. and van Horen, N. (2018), 'The (unintended?) consequences of the leverage ratio on repo market intermediation', *Working Paper* .

Krishnamurthy, A. (2002), 'The bond/old-bond spread', *Journal of Financial Economics* **66**(2-3), 463–506.

Krishnamurthy, A. and Vissing-Jorgensen, A. (2012), 'The aggregate demand for treasury debt', *Journal of Political Economy* **120**(2), 233–267.

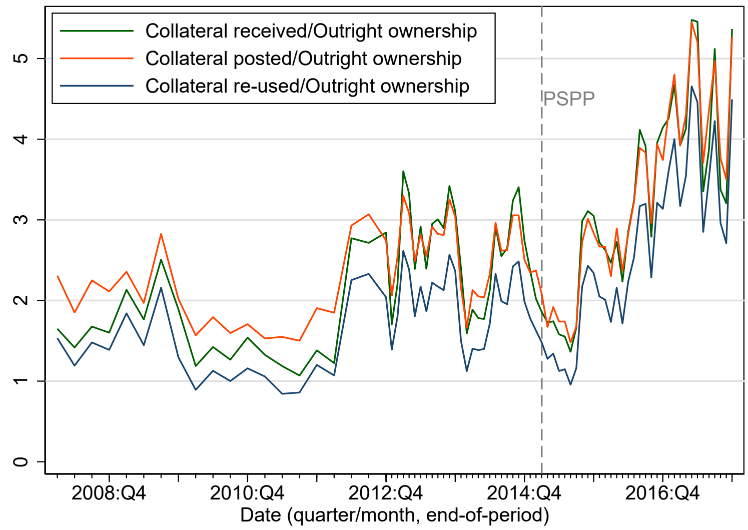
Lee, J. (2017), 'Collateral circulation and repo spreads', *Working Paper* .

Schlepper, K., Hofer, H., Riordan, R. and Schrimpf, A. (2018), 'The market microstructure of central bank bond purchases', *Journal of Financial and Quantitative Analysis* pp. 1–65.

Singh, M. (2011), 'Velocity of pledged collateral: Analysis and implications', *IMF Working Paper* (11-256).

Singh, M. and Aitken, J. (2010), 'The (sizable) role of rehypothecation in the shadow banking system', *IMF Working Paper* (10-172).

(a) Collateral over Outright Ownership



(b) Re-use Rate

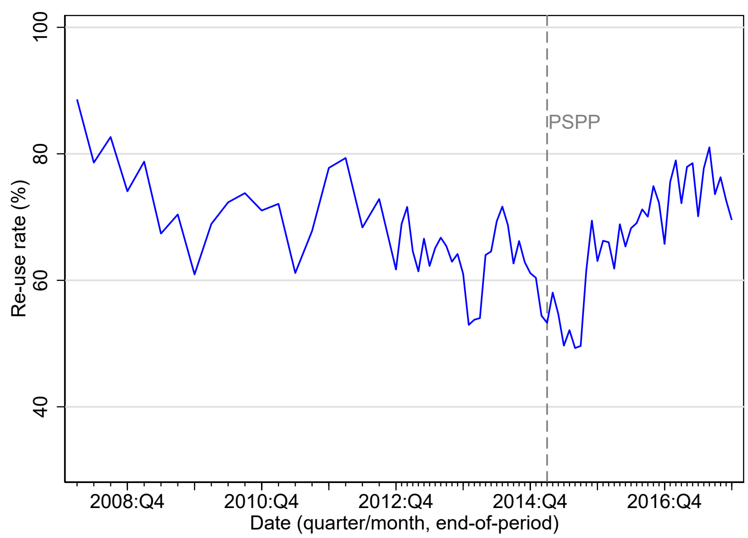


Figure 1: Collateral re-use over time

This figure shows the development of aggregate collateral re-use for European sovereign bonds with remaining maturity between 1 and 30 years. Figure 1(a) plots the multiplier obtained by dividing the amount of collateral received, posted, or re-used in European sovereign bonds by the amount of bonds owned outright. Figure 1(b) shows the development of the aggregate collateral re-use rate. The sample period is 2008-2017, 2008-2010 at quarterly frequency, 2013-2017 at monthly frequency.

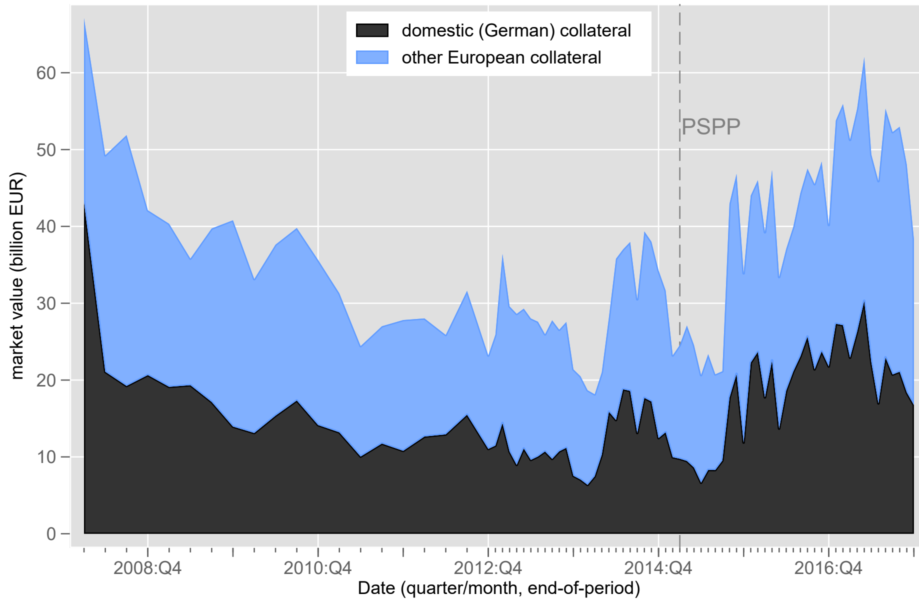


Figure 2: Collateral Re-used: Domestic vs. foreign
This figure shows the market value of collateral reused for domestic (i.e. German) collateral and collateral by other European countries in our sample. We consider European sovereign bonds with remaining maturity between 1 and 30 years. The sample period is 2008-2017, 2008-2010 at quarterly frequency, 2013-2017 at monthly frequency.

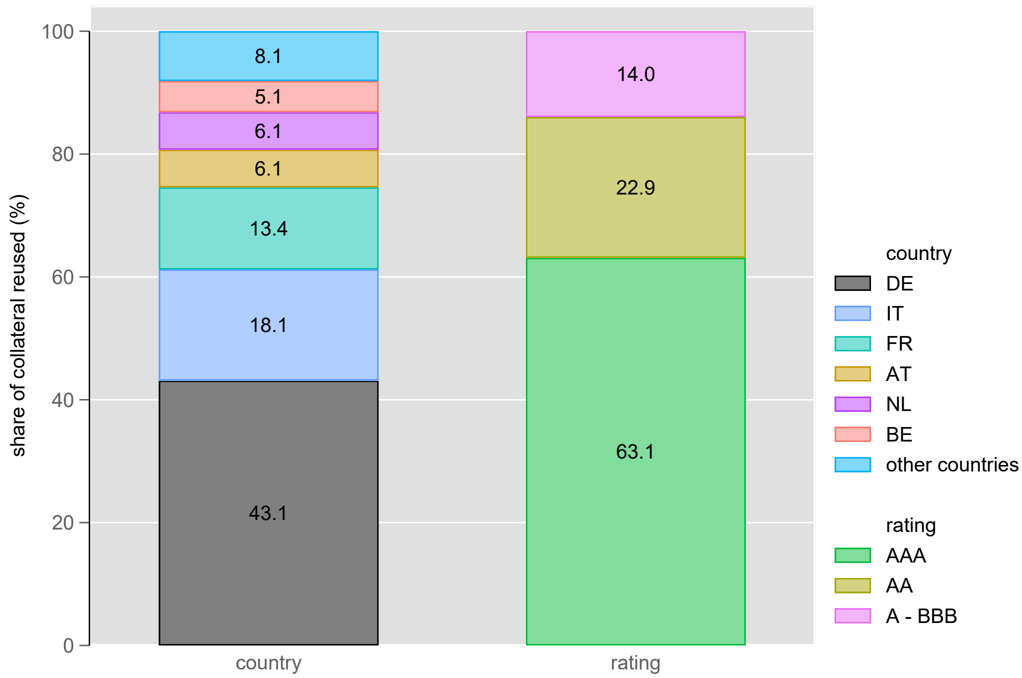


Figure 3: Collateral Reused by Issuer Country and Rating

This figure shows the overall share of collateral reused, computed as the time-series average, in our sample, by issuer country (left column) and by issuer rating (right column). The group *other countries* includes Spain, Finland, Greece, Ireland, and Portugal. We consider European sovereign bonds with a remaining maturity between 1 and 30 years. The sample period is 2008-2017 at quarterly frequency.

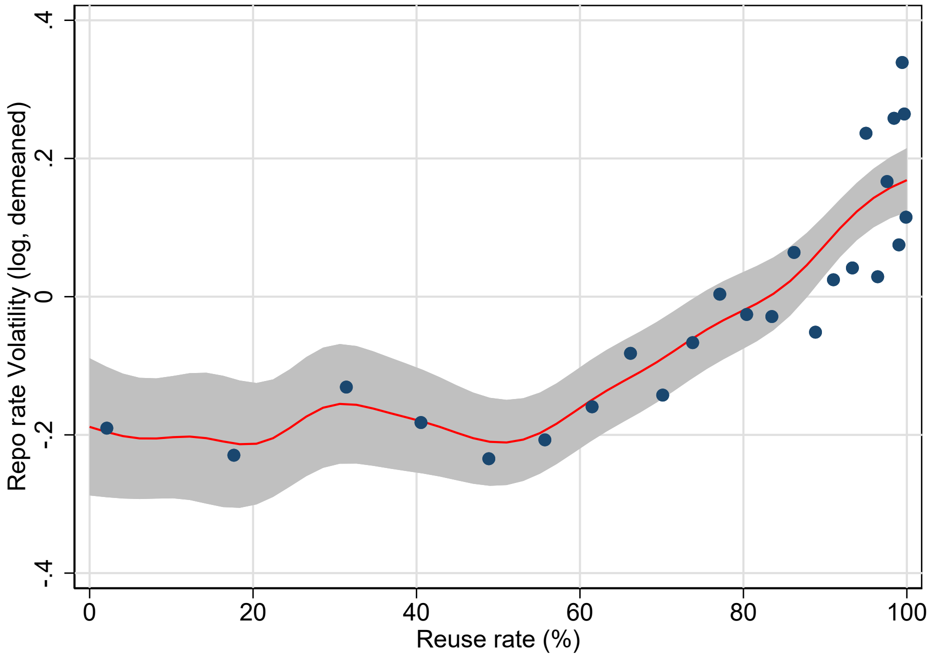


Figure 4:
re-use of collateral and repo rate volatility
This figure depicts the relationship between re-use rates and the volatility of repo rates. We measure repo rate volatility as the standard deviation of repo rates for each month. For visualization, we apply a binned scatter plot, for which we group variables into equal-sized bins along the x-axis, absorb time-fixed effects at the monthly level, and demean the volatility measure. The red line represents local mean smoothing with shaded areas indicating 95% confidence intervals. The sample consists of the monthly panel of German sovereign bonds with remaining maturity between 1 and 30 years. The sample period is March 2015 - December 2017.

Table 1:
Descriptive statistics: dependent variables

This table provides summary statistics of the dependent variables used in regressions throughout the paper. The sample period is March 2015 - December 2017 at monthly frequency. Panel A describes the dealer-bond-time panel consisting of European sovereign bonds with a remaining maturity between 1 and 30 years. The dependent variables describe monthly changes in the logarithmic amount reused (Δlog Reuse$_t$), reuse rate (ΔReuse Rate$_t$), and logarithmic amount of collateral received (Δ log(Coll. Rcvd.)$_t$). Panel B describes the bond-time panel consisting of German sovereign bonds with a remaining maturity between 1 and 30 years. The dependent variables are monthly changes in repo rate (ΔRepo Rate$_t$) and the repo rate volatility, measured as the logarithm of repo rates for each month (log(Repo Rate Volatility)$_t$).

Variable	Mean	Std. dev.	Percentiles 25th	50th	75th	N
Panel A: Reuse variables						
Δlog Reuse$_t$	0.05	9.07	-0.11	0.00	0.10	27,934
ΔReuse Rate$_t$	0.22	47.93	-0.98	0.00	1.43	27,934
Δ log(Coll. Rcvd.)$_t$	0.03	7.88	-0.00	0.00	0.00	27,934
Panel B: Repo rate variables						
ΔRepo Rate$_t$	-2.14	29.34	-6.98	-1.48	3.20	1,551
log(Repo Rate Volatility)$_t$	-3.02	1.13	-3.83	-3.20	-2.45	1,558

Table 2:
Asset purchases and collateral re-use

The table reports the results of a regression of changes in logarithmic amount of collateral reused (Δlog Reuse$_t$) on asset purchases in a dealer-bond-time panel at monthly frequency. The regression models is outlined in Equation (5). We account also for changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status. The sample period is March 2015 - December 2017. t-statistics based on clustered standard errors (bond×time) are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)	(5)
	Dependent variable: Δlog Reuse$_t$				
Asset purchases$_t$ (%)	0.16**	0.15**	0.16**	0.17**	0.21**
	(2.34)	(2.24)	(2.13)	(2.27)	(2.40)
Δ Amount outstanding$_t$	0.01	0.01	0.02	0.02	0.02*
	(1.25)	(1.14)	(1.51)	(1.53)	(1.96)
Dummy: On the run$_t$	0.45	0.46	0.67	0.68	0.66
	(1.16)	(1.12)	(1.43)	(1.48)	(1.40)
Dummy: Cheapest-to-deliver$_t$	0.16	0.09	0.15	0.11	0.06
	(0.46)	(0.26)	(0.38)	(0.28)	(0.14)
Constant	-0.12	-0.11	-0.14*	-0.15*	-0.18**
	(-1.64)	(-1.51)	(-1.68)	(-1.78)	(-2.11)
Fixed effects:					
dealer	yes	-	-	-	-
time	yes	-	-	-	-
bond	yes	yes	-	-	-
dealer×time	-	yes	yes	yes	yes
dealer×bond	-	-	yes	yes	yes
country×time	-	-	-	yes	-
maturity bucket×country×time	-	-	-	-	yes
R^2	.02074	.1017	.1122	.1285	.1634
N	27,927	27,744	27,006	27,006	26,936

Table 3:
Asset purchases and collateral re-use: intensive and extensive margin
The table reports the results of a regression of changes in collateral reuse on asset purchases in a dealer-bond-time panel at monthly frequency. The dependent variable in specifications (1) and (4) is changes in logarithmic amount of collateral reused (Δlog Reuse$_t$), where specification (1) repeats specification (5) in Table 2. In specifications (2) and (5) the dependent variable is changes in reuse rate (ΔReuse Rate$_t$), and in specifications (3) and (6) changes in the logarithmic amount of collateral received ($\Delta \log$(Coll. Rcvd.)$_t$). We account also for changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status. The sample consists of European sovereign bonds in specifications (1) - (3), and of German sovereign bonds in specifications (4) - (6). The remaining maturity is between 1 and 30 years. The sample period is March 2015 - December 2017. t-statistics based on clustered standard errors (dealer×time) are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
	European collateral			German collateral		
Dependent variable:	$\Delta \log$(Reuse Amt.)$_t$	ΔReuse Rate$_t$	$\Delta \log$(Coll. Rcvd.)$_t$	$\Delta \log$(Reuse Amt.)$_t$	ΔReuse Rate$_t$	$\Delta \log$(Coll. Rcvd.)$_t$
Asset purchases$_t$ (%)	0.21**	1.14**	0.15*	0.29**	1.65**	0.20
	(2.40)	(2.44)	(1.94)	(2.02)	(2.09)	(1.56)
Δ Amount outstanding$_t$	0.02*	-0.01	0.04***	0.03*	0.10	0.04***
	(1.96)	(-0.20)	(3.84)	(1.94)	(1.18)	(3.11)
Dummy: On the run$_t$	0.66	6.32**	0.56	0.66	5.56	0.09
	(1.40)	(2.45)	(1.28)	(0.65)	(0.98)	(0.09)
Dummy: Cheapest-to-deliver$_t$	0.06	0.57	0.01	0.00	0.00	0.00
	(0.14)	(0.27)	(0.03)	(0.01)	(0.00)	(0.00)
Constant	-0.18**	-1.04**	-0.16**	-0.29	-1.62	-0.25
	(-2.11)	(-2.25)	(-2.05)	(-1.62)	(-1.64)	(-1.57)
Fixed effects:						
dealer×time	yes	yes	yes	yes	yes	yes
dealer×bond	yes	yes	yes	yes	yes	yes
maturity bucket×country×time	yes	yes	yes	yes	yes	yes
R^2	.1634	.1698	.1291	.1827	.1868	.1378
N	26,936	26,936	26,936	7,636	7,636	7,636

Table 4:
The Effect of asset purchases on Repo rates

The table reports the results of a regression of changes in repo rate (ΔRepo Rate$_t$) on asset purchases in a bond-time panel at monthly frequency. We account also for changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status. In specifications (2) and (4) we additionally account for the lagged level of collateral re-use normalized by outright ownership in the same bond, and its interaction with asset purchases. The full regression models is outlined in Equation (7). The sample consists of German sovereign bonds with a remaining maturity between 1 and 30 years. The sample period is March 2015 - December 2016 in specifications (1) and (2) (before the enhancement of securities lending facilities), and in specifications (3) and (4) from January 2017 - December 2017 (after the enhancement of securities lending facilities). t-statistics based on standard errors clustered at the bond level are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
	No-enhanced securities lending period		enhanced securities lending period	
	Dependent variable: ΔRepo Rate$_t$			
Asset purchases$_t$ (%)	-1.39***	-1.49***	-1.03*	-1.16
	(-3.60)	(-3.50)	(-1.69)	(-1.39)
Δ Amount outstanding$_t$	0.36	0.97*	0.19	0.14
	(1.55)	(1.67)	(1.39)	(0.84)
Dummy: On-the-run$_t$	-11.74	-27.29	2.45	5.40
	(-1.17)	(-1.54)	(0.36)	(0.75)
Dummy: Cheapest-to-deliver$_t$	-2.73*	-1.78	-5.39	-6.03
	(-1.91)	(-1.06)	(-0.65)	(-0.71)
$\log(\textit{Re-use/Outright ownership})_{i,t-1}$		0.26		0.67**
		(1.01)		(2.26)
Asset purchases$_t$ (%) $\times \log(\textit{Re-use/Outright ownership})_{i,t-1}$		-0.42***		0.07
		(-3.62)		(0.34)
Constant	-5.55***	-5.52***	8.72***	7.66***
	(-14.19)	(-11.24)	(18.04)	(12.41)
Fixed effects:				
bond	yes	yes	yes	yes
maturity bucket×time	yes	yes	yes	yes
R^2	.8079	.8163	.8147	.8166
N	1,043	1,005	506	496

Table 5:
Collateral re-use and repo market volatility

The table reports the results of a regression of (logarithmic) repo rate volatility (log(Repo Rate Volatility)$_t$) on determinants of collateral supply and demand. We measure repo rate volatility as the logarithm of the standard deviation of repo rates for each month. The dummy *reuse rate high* is 1 when the aggregate reuse rate in a bond is above 80%. We account also for changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status, and in specifications (2) and (4) we additionally account for the lagged overall share of bond issuance that was purchased and the lagged repo rate. The full regression models is outlined in Equation (8). The sample consists of German sovereign bonds with a remaining maturity between 1 and 30 years and the sample period is March 2015 - December 2017. To avoid that extreme spikes in repo rates at year ends are driving our results we exclude these observations from the analysis in specifications (3) and (4). t-statistics based on standard errors clustered at the bond level are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
	Full Sample Period		Excluding year ends	
	Dependent variable: log(Repo Rate Volatility)$_t$			
Dummy: reuse rate high$_{t-1}$	0.08**	0.06**	0.09**	0.07*
	(2.61)	(2.04)	(2.43)	(1.99)
Yield$_{t-1}$ (%)	-0.02	-0.01	-0.01	0.00
	(-0.38)	(-0.17)	(-0.15)	(0.07)
Amount outstanding$_{t-1}$ (log)	-0.30	0.10	-0.32	0.14
	(-1.26)	(0.55)	(-1.18)	(0.63)
Dummy: on-the-run$_t$	0.19	0.41***	0.18	0.44**
	(1.35)	(2.87)	(1.08)	(2.45)
Dummy: Cheapest-to-deliver$_t$	0.19***	0.18***	0.21***	0.21***
	(2.95)	(3.21)	(3.20)	(3.65)
Overall share purchased$_{t-1}$		-0.00		-0.00
		(-0.76)		(-0.57)
Repo rate$_{t-1}$		-0.77***		-0.80***
		(-5.15)		(-5.11)
Constant	4.09	-5.70	4.19	-6.95
	(0.72)	(-1.37)	(0.66)	(-1.32)
Fixed effects:				
bond	yes	yes	yes	yes
time	yes	yes	yes	yes
R^2	.8651	.8666	.7834	.7871
N	1,487	1,381	1,360	1,264

Internet Appendix accompanying
"Safe asset shortage and collateral re-use"

Table IA.1:
Descriptive statistics: re-use rates

This table shows summary statistics and correlations of collateral re-use rates, employing the three different measures for collateral re-use activity. The sample consists of the security-level panel of European sovereign bonds with remaining maturity between 1 and 30 years. The sample period is 2008 - 2017 at quarterly frequency.

			Std.	Percentiles			Correlation		
Row	Variable	Mean	dev.	25th	50th	75th	(1)	(2)	(3)
(1)	*re-use rate*^{lower} (%)	53.2	38.3	7.6	61.2	90.9	1		
(2)	*re-use rate*$^{prop.}$ (%)	56.1	37.4	17.3	65.4	91.9	0.97	1	
(3)	*re-use rate*^{upper} (%)	59.5	38.4	20.0	72.0	96.2	0.90	0.97	1

Table IA.2:
Asset purchases and collateral re-use: intensive and extensive margin
Robustness check: Using alternative re-use measures.

This table provides a robustness check to the analysis of Table 3 using the upper- and lower-bound re-use as dependent variable in the regression instead. The dependent variable is changes in logarithmic amount of collateral re-used (Δlog Re-use$_t$) in specifications (1) - (3), and changes in re-use rate (ΔRe-use Rate$_t$) in specifications (4) - (6). Specifications (2) and (5) are the benchmark, and are identical to specifications (1) and (2) in Table 3, respectively. In specifications (1) and (4) we emply the lower bound measure for re-use instead, and in specifications (3) and (6) the upper bound measure. We account also for changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status. The sample consists of European sovereign bonds with a remaining maturity between 1 and 30 years. The sample period is March 2015 - December 2017. t-statistics based on clustered standard errors (dealer×time) are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	Δ log(Re-use Amt.)$_t$			ΔRe-use Rate$_t$		
Re-use computation:	Lower bound	Prop. measure	Upper bound	Lower bound	Prop. measure	Upper bound
Asset purchases$_t$ (%)	0.20**	0.21**	0.21**	1.07**	1.14**	1.21**
	(2.31)	(2.40)	(2.37)	(2.29)	(2.44)	(2.52)
Δ Amount outstanding$_t$	0.01	0.02*	0.02**	-0.02	-0.01	0.01
	(1.18)	(1.96)	(2.04)	(-0.41)	(-0.20)	(0.16)
Dummy: On the run$_t$	0.65	0.66	0.65	5.86**	6.32**	6.27**
	(1.37)	(1.40)	(1.38)	(2.30)	(2.45)	(2.36)
Dummy: Cheapest-to-deliver$_t$	0.16	0.06	0.04	0.66	0.57	0.61
	(0.42)	(0.14)	(0.11)	(0.31)	(0.27)	(0.27)
Constant	-0.16*	-0.18**	-0.18**	-0.92**	-1.04**	-1.16**
	(-1.86)	(-2.11)	(-2.10)	(-1.99)	(-2.25)	(-2.42)
Fixed effects:						
dealer×time	yes	yes	yes	yes	yes	yes
dealer×bond	yes	yes	yes	yes	yes	yes
maturity bucket×country×time	yes	yes	yes	yes	yes	yes
R^2	.156	.1634	.1634	.1663	.1698	.1704
N	26,936	26,936	26,936	26,936	26,936	26,936

Table IA.3:
Adjustment to re-use rates necessary to compensate supply reductions.
This table provides a robustness check to the analysis in Section 4.3 using a wide set of potential parameters. Specifically we compute the re-use rate *re-use rate′* that is necessary to compensate for a reduction by one percent in collateral supply (*base amount* in Equation (6)), given the initial *re-use rate* and haircut. Δ*re-use rate* gives the corresponding increase in the re-use rate in percentage points.

re-use rate (%)	haircut (%)	*re-use rate′* (%)	Δ*re-use rate* (%)
10.00	2.00	10.92	0.92
20.00	2.00	20.82	0.82
30.00	2.00	30.72	0.72
40.00	2.00	40.62	0.62
50.00	2.00	50.52	0.52
60.00	2.00	60.42	0.42
70.00	2.00	70.32	0.32
80.00	2.00	80.22	0.22
90.00	2.00	90.12	0.12
95.00	2.00	95.07	0.07
99.00	2.00	99.03	0.03
10.00	3.00	10.93	0.93
20.00	3.00	20.83	0.83
30.00	3.00	30.73	0.73
40.00	3.00	40.63	0.63
50.00	3.00	50.53	0.53
60.00	3.00	60.43	0.43
70.00	3.00	70.33	0.33
80.00	3.00	80.23	0.23
90.00	3.00	90.13	0.13
95.00	3.00	95.08	0.08
99.00	3.00	99.04	0.04

Table IA.4:
The Effect of asset purchases on Repo rates
Robustness check: Extended sample of bonds.

This table provides a robustness check to the analysis of Table 4 using a more general universe of bonds. We consider domestic and non-domestic sovereign bonds for which we observe a re-use activity comparably to domestic collateral. Specifically, we standardize the aggregate amount of collateral re-use of all dealers in our sample by dividing it through the total amount outstanding. For a bond to be included in the sample, we require it to be greater or equal to the 20th percentile of the domestic collateral distribution. The table reports the results of a regression of changes in repo rate (ΔRepo Rate$_t$) on asset purchases in a bond-time panel at monthly frequency. We account also for changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status. In specifications (2) and (4) we additionally account for the lagged level of collateral re-use normalized by outright ownership in the same bond, and its interaction with asset purchases. The full regression models is outlined in Equation (7). The remaining maturity of all bonds is between 1 and 30 years. The sample period is March 2015 - December 2016 in specifications (1) and (2) (before the enhancement of securities lending facilities), and in specifications (3) and (4) from January 2017 - December 2017 (after the enhancement of securities lending facilities). t-statistics based on standard errors clustered at the bond level are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
	No-enhanced securities lending period		enhanced securities lending period	
	Dependent variable: ΔRepo Rate$_t$			
Asset purchases$_t$ (%)	-1.08***	-1.22***	-1.19**	-1.26*
	(-3.76)	(-4.23)	(-2.09)	(-1.68)
Δ Amount outstanding$_t$	0.29	0.64	0.21*	0.17
	(1.60)	(1.62)	(1.83)	(1.31)
Dummy: On-the-run$_t$	-8.03	-16.75	0.17	1.95
	(-1.13)	(-1.47)	(0.03)	(0.38)
Dummy: Cheapest-to-deliver$_t$	-3.43**	-2.64	-5.25	-5.83
	(-2.14)	(-1.49)	(-0.62)	(-0.67)
$\log(\textit{Re-use/Outright ownership})_{i,t-1}$		0.29		0.63**
		(1.04)		(2.14)
Asset purchases$_t$ (%) $\times$ $\log(\textit{Re-use/Outright ownership})_{i,t-1}$		-0.39***		0.11
		(-3.03)		(0.52)
Constant	-5.40***	-5.39***	7.76***	7.30***
	(-16.95)	(-15.38)	(17.87)	(14.99)
Fixed effects:				
bond	yes	yes	yes	yes
maturity bucket×country×time	yes	yes	yes	yes
R^2	.8109	.8150	.8213	.8233
N	1,340	1,288	676	654