DEUTSCHE BUNDESBANK
EUROSYSTEM

Discussion Paper

Deutsche Bundesbank
No 39/2021

Safe asset shortage and collateral reuse

Stephan Jank
(Deutsche Bundesbank)

Emanuel Moench
(Deutsche Bundesbank, Goethe University Frankfurt and CEPR)

Michael Schneider
(Deutsche Bundesbank and SAFE – Goethe University Frankfurt)

Deutsche Bundesbank, Wilhelm-Epstein-Straße 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-0

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

Internet http://www.bundesbank.de

ISBN 978–3–95729–847–8
ISSN 2749–2958

Non-technical summary

Research Question

Safe assets play an important role as store of value and as collateral in financial transactions, such as repurchase agreements (repos). Increasing imbalances in the supply and demand of high-quality assets have raised concerns about a shortage of safe assets. An important mechanism how market participants can adjust to a shortage of safe assets is collateral reuse. That is, market participants reuse collateral received from one transaction as collateral in another transaction with a different counterparty. In this paper, we study this "collateral reuse channel".

Contribution

We use a unique regulatory dataset on German dealer banks' (re-)use of collateral combined with information on asset purchases through the European Central Bank's public sector purchase programme (PSPP). We study how dealers adjust their reuse of collateral in response to the scarcity induced by such purchases, and how this reuse in turn affects the repo market.

Results

We find that aggregate reuse activity of Euro area sovereign collateral is high, with average reuse rates between 50-90% and reuse amounting to up to seven times the outright ownership. Banks substantially increase their reuse in response to central bank asset purchases. Moreover, we show that repo rates are less sensitive to asset purchases at low levels of reuse, when the banking system can easily supply additional collateral through reuse. Instead, at high levels of reuse repo rates are more sensitive to scarcity and also more volatile. Our results show that collateral reuse may on the one hand alleviate shocks, but on the other hand contribute to their amplification.

Nichttechnische Zusammenfassung

Fragestellung

Sichere Vermögenswerte spielen eine entscheidende Rolle als Wertaufbewahrungsmittel und als Sicherheiten bei Finanztransaktionen wie Repogeschäften. Das zunehmende Ungleichgewicht zwischen Angebot und Nachfrage bei hochqualitativen Wertpapieren hat Bedenken hinsichtlich einer Verknappung sicherer Vermögenswerte aufkommen lassen. Marktteilnehmer können durch Wiederverwendung von Sicherheiten ("collateral reuse") auf einen Mangel an solchen Vermögenswerten reagieren. Dabei setzen sie Sicherheiten, die sie im Rahmen einer Transaktion erhalten haben, bei einer weiteren Transaktion mit einem anderen Geschäftspartner wieder ein. Dieses Forschungspapier untersucht die Bedeutung der Wiederverwendung von Sicherheiten für den Repomarkt.

Beitrag

Wir stützen unsere Analyse auf einen einzigartigen aufsichtsrechtlichen Datensatz, der die Wiederverwendung von Sicherheiten durch deutsche Händlerbanken quantifiziert. Diesen kombinieren wir mit granularen Daten zu den Anleihekäufen im Rahmen des Programms zum Ankauf von Wertpapieren des öffentlichen Sektors (PSPP) der Europäischen Zentralbank (EZB). Dabei gehen wir der Frage nach, wie Händler die Wiederverwendung von Sicherheiten anpassen, wenn diese im Zuge der Anleihekäufe knapp werden, und welche Auswirkungen sich daraus für den Repomarkt ergeben.

Ergebnisse

Unsere Ergebnisse zeigen, dass Staatsanleihen aus dem Euroraum als Sicherheiten mit einer hohen durchschnittlichen Quote von 50% bis 90% wiederverwendet werden. Im Verhältnis zum direkten Wertpapierbesitz beläuft sich die Wiederverwendung bis auf das Siebenfache des Bestands. Als Reaktion auf Anleihekäufe durch die EZB weiten die Banken die Wiederverwendung von Sicherheiten deutlich aus. Bei einem geringen Wiederverwendungsgrad, wenn das Bankensystem also im Wege der Wiederverwendung problemlos zusätzliche Sicherheiten bereitstellen kann, reagieren Reposätze weniger sensibel auf Anleihekäufe. Bei einem hohen Wiederverwendungsgrad weisen die Reposätze hingegen eine stärkere Sensitivität gegenüber der Verknappung sicherer Vermögenswerte und auch eine höhere Volatilität auf. Unsere Ergebnisse zeigen, dass die Wiederverwendung von Sicherheiten sowohl zur Abmilderung von Schocks, aber auch zu deren Amplifizierung beitragen kann.

DEUTSCHE BUNDESBANK DISCUSSION PAPER NO 39/2021

Safe asset shortage and collateral reuse*

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

July 26, 2021

Abstract

The reuse of collateral can support the efficient allocation of assets in the financial system. Exploiting a novel dataset, we quantify banks' collateral reuse at the security level. We show that banks substantially increase their reuse of collateral in response to scarcity induced by central bank asset purchases. Repo rates are less sensitive to purchase-induced scarcity at low levels of reuse, when the banking system can easily supply collateral through reuse. Repo rates are more sensitive to scarcity and more volatile at high levels of reuse, highlighting the trade-off between the shock absorption and shock amplification effects of collateral reuse.

Keywords: safe assets, government bonds, collateral reuse, rehypothecation, repo market, securities lending

JEL: E4, E5, G1, G2

*We thank Darrell Duffie, Peter Egger, Heiko Hofer, Sebastian Infante (discussant), Toomas Laarits (discussant), Julien Mazzacurati, Jose-Louis Peydro, Maxim Pinkovskiy, Angelo Ranaldo, Jean-Paul Renne (discussant), Kathi Schlepper, Zorka Simon and seminar and conference participants at Deutsche Bundesbank, Goethe University, SFS Cavalcade, ECB Money Market Conference, and the CAMF & Bank of England 8th Asset Pricing Workshop 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 issuers in recent years. 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 reuse 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 reuse 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 reuse 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 reused in unrelated transactions is referred to as "collateral velocity". Conceptually, the collateral velocity resembles the well-known money multiplier. As collateral can be reused multiple times, even a modest increase in collateral reuse would contribute to a significant increase in collateral available for market transactions. The more often a security is reused 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, 2020). Although collateral reuse increases collateral availability, it may also generate risks for financial stability, including the build-up of excessive leverage, growing interconnectedness, and hence contribute to an amplification of shocks (Brumm, Kubler, Grill and Schmedders, 2018; FSB, 2017*b*).

Reuse 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 reused by financial intermediaries. Very few studies quantify collateral reuse, and only at the dealer level, relying on dealers' annual reports (Singh and Aitken, 2010; Singh, 2011) or on supervisory data (Infante, Press and Strauss, 2018; Infante, Press and Saravay, 2020). Granular data on how dealers manage their collateral has not been available thus far. We fill this gap by making use of a unique regulatory dataset that provides comprehensive *security-by-security* information on dealers' collateral positions. Specifically, we exploit a unique feature of the Bundesbank's Securities Holdings Statistics (SHS), which not only provides security-level information on German banks' individual 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 reuse activity at the *security* level, which is essential when studying scarcity effects.

Central bank purchases of government bonds provide a useful laboratory to study the effects of safe asset scarcity on collateral reuse. Under its Public Sector Purchase Programme (PSPP), the Eurosystem bought about EUR 2.2 trillion of member countries' sovereign debt securities from 2015 to date. These sovereign debt purchases correspond to almost 30 percent of the total amount outstanding and thus represent a significant reduction of collateral available to market participants. 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. This allows us to study how the exogenous reduction in available collateral affects dealers' reuse activity.

We find that the rate at which dealers reuse incoming euro area sovereign collateral is high, fluctuating between 50% and 90% during our sample period which covers the years 2008 through 2017. Notably, the reuse rate increased strongly after the inception of the PSPP. The amount of collateral reused is also substantial with regard to the outright ownership in these bonds, and increased from one and a half times dealers' own holdings before the start of the PSPP to more than seven times at the end of the sample.

Using proprietary security-level information on PSPP purchases of European government bonds, we analyze how dealers adjust collateral reuse in response to a reduced availability of safe assets. We document a sizable adjustment in reuse when collateral becomes more scarce: an asset purchase of one percent of the bond's outstanding amount increases the collateral reuse in that bond by 0.15% in the same month. This increase is driven by two channels. On the one hand dealers increase the rate at which they reuse collateral that they already have available by 0.89 percentage points. On the other hand dealers obtain 0.11% more collateral for reuse from other market participants given the same reduction in collateral supply via the PSPP.

To what degree does dealers' endogenous adjustment of collateral reuse mitigate safe asset scarcity? To analyze this question we study the security-level reuse of German federal government bonds (Bunds), which is the collateral most commonly used by German dealer banks. An asset purchase of 1% of the amount outstanding reduces Bunds' specific collateral repo rates by 1.05 basis points, thus making it more costly to borrow such securities. We show that dealers mitigate this Bund scarcity by increasing collateral reuse, but their ability to do so crucially depends on the prevailing level of collateral reuse in a given bond. A one standard deviation higher reuse raises the sensitivity of the repo rate to asset purchases by about two thirds relative to the baseline effect. These results highlight the importance of collateral reuse in compensating asset scarcity. Repo rates are less sensitive to scarcity induced by asset purchases at low levels of reuse, and more so when reuse activity is already high and thus the possibility to increase reuse is limited.

In principle, dealers can substitute scarce bonds with similar securities in their collateral portfolio. Yet, a prior literature (Brand, Ferrante and Hubert, 2019; Cœuré, 2019; Schaffner, Ranaldo and Tsatsaronis, 2019) has documented some fragmentation of the European collateral market. We analyze the spillover of asset purchase induced scarcity on the reuse activity in bonds with similar rating and maturity. In line with some level of fragmentation, we find evidence for substitution of collateral being asymmetric. Specifically we show that reuse in German Bunds is less sensitive to scarcity in other high-quality collateral than vice versa.

A potential side effect of high collateral reuse 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 reuse and the volatility of repo rates. Controlling for different demand and supply factors in the repo market, we find that for a one standard deviation higher reuse, repo market volatility increases by up to 4% in the next month.

In sum, our findings highlight the importance of the collateral reuse channel in the context of safe asset scarcity: financial market participants endogenously respond to a shortage of safe assets by enhancing the reuse of collateral. At the extensive margin they seek more collateral from counterparties, and at the intensive margin they reuse available collateral at a higher rate. While the associated increase in effective collateral availability dampens the impact of asset purchases on scarcity premia, the volatility of these premia increases with the degree of reuse activity. Hence, our paper is the first to empirically document a trade-off between the shock absorption and shock amplification effects of collateral reuse.

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 (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 increased 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 reuse 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 reuse in financial markets. In general, this literature acknowledges a trade-off between economic efficiency and financial stability with respect to collateral reuse (e.g. Lee, 2017). 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. Infante (2019) highlights that runs may arise due to collateral reuse. In Andolfatto, Martin and Zhang (2017) reuse of collateral improves the efficient allocation of liquidity. In Brumm et al. (2018) moderate collateral reuse improves welfare due to more efficient risk sharing, but excessive reuse increases leverage and volatility in the economy, reducing welfare. In line with this mechanism, we document a direct link between the level of reuse and repo rate volatility.

To quantify the magnitude of reuse researchers have initially resorted to dealers' annual reports (Singh and Aitken, 2010; Singh, 2011; Kirk, McAndrews, Sastry and Weed, 2014). More recently, Infante et al. (2020) and Infante and Saravay (2020) quantify dealer-level collateral reuse activity from U.S. confidential supervisory data. Consistent with our findings, the latter paper shows that Treasury reuse increases as Federal Reserve asset purchases reduce the supply of available securities. Our dealer-security-level data additionally allow us to study the compensating effect of reuse on asset scarcity, scarcity-induced reuse spillovers between securities, as well as the implications of reuse activity on repo rate volatility. Fuhrer, Guggenheim and Schumacher (2016) construct a measure of collateral reuse in the Swiss repo market from transaction data, showing that collateral reuse decreases with the availability of collateral.[1] Our dataset captures the reuse of collateral not only in the 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 (2020) 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 reuse activities and document that it is negatively related to bonds' specialness premia, suggesting an endogenous market reaction to scarcity. This is consistent with our finding that reuse increases in response to a reduction of available high-quality collateral, and that scarcity premia are lower for securities with a higher level of reuse.

Finally, we contribute to the literature on repo markets and bond specialness (e.g. Jordan and Jordan, 1997; Krishnamurthy, 2002). Several authors study the scarcity effects of central bank asset purchase programs on the repo market in the U.S. and the euro area, providing evidence that such purchases raise specialness spreads (D'Amico, Fan and Kitsul, 2018; Jank and Moench, 2018; Brand et al., 2019). In a recent study, Arrata, Nguyen, Rahmouni-Rousseau and Vari (2020) also document that purchases through the ECB's public sector purchase program (PSPP) lead to a reduction in repo rates. Moreover, Corradin and Maddaloni (2020) show that the ECB's securities markets program (SMP) increases the probability of failures-to-deliver. We add to this literature by highlighting that the sensitivity of repo rates to asset purchases documented in previous studies depends on dealers' reuse activity. In using scarce collateral more effectively dealers reduce the impact of purchases on repo market specialness. However, when reuse activity is already

[1] Fuhrer et al. (2016) propose an algorithm to quantify collateral reuse 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 reused collateral. This is a rather low level of reuse compared to the estimates from dealers' annual reports (70-80%). The low estimate for reuse is likely due to the fact that the authors only consider repos denominated in Swiss francs and also cannot factor in securities lending transactions.

high, this compensatory effect is mitigated, leading to a higher sensitivity of repo rates to asset purchases.

2 Measuring collateral reuse

Following the broad definition of the FSB (2017*b*), collateral reuse 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 incoming collateral is eligible for reuse, the financial institution can reuse the security to support another such transaction. Received collateral can also be used to establish a short position. The definition of collateral reuse 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' incoming and outgoing collateral from securities financing transactions, which include reverse repo transactions and securities lending. Importantly, collateral received from these transactions is eligible for reuse 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 reuse 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 reuse, respectively.

To compute collateral reuse at the dealer-security level we rely on the Bundesbank's Securities Holdings Statistics (SHS) which provides security-level data on German banks' 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 incoming and outgoing collateral 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 incoming and outgoing collateral is to avoid double counting in securities holdings. We utilize this information to compute security-specific reuse activity at the bank level.[2] As securities lending and repo transactions in Europe almost always involve full temporary transfer of title of the underlying security, we assume that all incoming collateral in the SHS is eligible for reuse.

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.[3] Before calculating our reuse measures we apply the following filters to the data. We employ a plausibility check to our data by checking whether the outgoing collateral exceeds the sum of amount owned outright and incoming collateral. 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 outgoing collateral is zero both for the current and the previous period.

Figure 1(a) describes the dynamics of the aggregate incoming and outgoing collateral, normalized by the outright ownership across dealers and securities. Both metrics move in lockstep, already suggesting that much of the received collateral is reused when collateral is posted. Moreover, the figure shows that both incoming and outgoing collateral considerably exceed the dealers' outright holdings. Both metrics range between 2 and 9 in our sample period. In particular, we see a strong increase in incoming and outgoing collateral after the introduction of the PSPP.

[2]While the data do not contain any information on haircuts, they typically do not feature much variation, especially for safe assets, such as highly-rated government bonds (Gorton et al., 2020).

[3]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.

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

$$Reuse_{ij} = \left(\frac{Incoming\ collateral_{ij}}{Incoming\ collateral_{ij} + Outright\ ownership_{ij}} \right) \times Outgoing\ collateral_{ij}, \quad (1)$$

where $Incoming\ collateral_{ij}$ is the market value of bond i received as collateral by dealer j, $Outgoing\ collateral_{ij}$ is the market value of bond i posted as collateral or sold short by dealer j, and $Outright\ ownership_{ij}$ is the market value of dealer j's outright ownership of bond i. The measure assumes proportional use of own assets and incoming collateral when posting collateral. This is in line with the responses received by market participants to a call for evidence by the FSB. According to the FSB (2017*a*) survey, market participants do not generally distinguish between own securities or securities originating from another collateralized transaction when posting collateral. We discuss robustness with respect to this assumption below. Figure 1(a) shows the aggregate amount of collateral reused, normalized by the outright ownership. The ratio is always slightly lower than for incoming and outgoing collateral. It closely tracks the other two metrics, including the sharp increase during the PSPP period.

An important aspect of repo markets is central clearing. Central counterparties (CCPs) provide several advantages, such as netting and clearing of bilateral positions. However, CCPs may also impede collateral reuse. In Europe trading platforms and associated CCPs tend to specialise in particular segments of the market (Schaffner et al., 2019). Such specialization reduces the scope for netting to market participants. Our data does not provide information on banks' counterparties or the use of central clearing. But even if a fraction of dealers' collateral is excluded from reuse by CCPs, our measure captures collateral reuse that takes place despite such frictions.

To capture the intensive margin of reuse activity, we compute the rate at which dealer j reuses collateral in bond i as follows:

$$Reuse\ rate_{i,j} = \left(\frac{Reuse_{i,j}}{Incoming\ collateral_{i,j}}\right). \tag{2}$$

The reuse rate thus measures the fraction of incoming collateral that has been reused by a dealer bank in a specific security. It indicates how extensively the dealer uses its collateral resources and therefore sometimes referred to as "collateral efficiency" (Kirk et al., 2014). When there is no incoming collateral we define $reuse\ rate_{i,j} := 0$. We compute the security-specific $reuse\ rate_i$ by aggregating for a specific bond i the amount of incoming and reused collateral over all German dealers.

Figure 1(b) shows the aggregate reuse rate for European sovereign bonds over time. Consistent with anecdotal evidence, collateral reuse declined in times of market stress such as the global financial crisis of 2007-2008 and the European sovereign debt crisis. Moreover, there appears to be a decline in the reuse 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 reuse 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 reuse activity, respectively. As an upper bound to the amount of collateral reused we define (FSB, 2016):

$$Collateral\ reused_{ij}^{upper} = \min(Incoming\ collateral_{ij}, Outgoing\ collateral_{ij}). \tag{3}$$

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

$$Collateral\ reused_{ij}^{lower} = \max((Outgoing\ collateral_{ij} - Own\ assets_{ij}), 0) \tag{4}$$

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

Consider the following example for illustration of the three reuse measures. Dealer A posts 90 million EUR of a specific bond as collateral. This outgoing collateral can in principle originate from two sources: own assets or incoming collateral. In our example dealer A received 100 million EUR as collateral and owns outright 20 million EUR. Hence, the lower bound of collateral reused 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 incoming collateral of which she sources the remaining amount (90-20 = 70 million EUR). So, we know for sure that the dealer reuses 70 million EUR of its incoming collateral. The proportional measure of collateral reuse is given by $(100/(100 + 20)) \times 90 = 75$ million EUR. Here the dealer obtains collateral proportionally from the two sources, of which the incoming collateral amounts to $100/(100 + 20) = 83.3\%$. The upper bound of collateral reuse is given by $\min(100, 90) = 90$ million EUR. Here the dealer fully sources her outgoing collateral with incoming collateral. Relating the amount of collateral reused to the amount of incoming collateral (100 million EUR), the corresponding reuse 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 outgoing collateral has to come from incoming collateral. Following the same logic, if the outright ownership becomes small relative to incoming and outgoing collateral the three measures converge. Indeed, we find that the three measures yield very similar reuse rates in our sample.[4] In what follows, we will thus focus on the proportional measure of collateral reuse since it most closely resembles actual market practices. As a robustness check we

[4]See Table IA.1. The correlation of the reuse rate obtained using the proportional measure with the reuse rate from both the upper and lower bound is very high at 0.98. The upper and lower measure also have a correlation of 0.93.

repeat our main analyses in the Internet appendix using the upper/lower bound approach, and obtain very similar results.[5]

Figure 2 shows the aggregate market value of collateral reused over time, where we distinguish between domestic (i.e. German) sovereign bonds and bonds issued by other euro area countries. The aggregate value of reused collateral was highest at the beginning of our sample in 2007 at more than 100 billion EUR and decreased to less than 40 billion EUR in early 2014. Reuse volume picked up again towards the end of 2015 and was at around 70 billion EUR during 2017. The share of domestic collateral is substantial, ranging between 35.8% and 65.2%. In Figure 3 we report the average share of collateral reused by issuer country and rating, respectively. German bonds, on average, account for 48.5% of market value, while Italian and French bonds represent 18.2% and 12.4% of the total, respectively. French, Austrian and Dutch bonds take up 5.0%, 4.4% and 3.7%, respectively. In terms of ratings, the vast majority (65.4%) of reused collateral is AAA-rated and 20.9% has a AA rating. 13.8% are rated either A or BBB.

3 Collateral reuse adjustment to scarcity of safe assets

In this section, we empirically analyze how dealers react to changes in collateral scarcity. We first investigate how dealers adjust their reuse rate to collateral scarcity. We then study to what degree dealers also adjust the amount of incoming collateral, and the resulting (joint) effect on the amount of collateral reused.

3.1 Reuse rate 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 purchases of government bonds via its Public Sector Purchase Program (PSPP) as our measure of variation in safe asset shortage. The PSPP was announced on 22 January 2015 and consists of the large-scale

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

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.[6] In our analysis, we make use of proprietary security-level information on Eurosystem PSPP purchases.[7]

Our approach resembles that of the literature which studies the effects of central banks' asset purchases on bond yields (De Santis and Holm-Hadulla, 2017; Schlepper, Hofer, Riordan and Schrimpf, 2018) or on bond specialness (D'Amico et al., 2018; Arrata et al., 2020; Corradin and Maddaloni, 2020). Our basic panel regression specification is the following:

$$\begin{aligned} \Delta reuse\ rate_{i,j,t} &= \beta_0 + \beta_1 Purchase_{i,t} + \gamma' \text{Controls}_{i,t} \\ &\quad + \alpha_{j,t} + \alpha_{i,j} + \alpha_{m,c,t} + \varepsilon_{i,j,t}, \end{aligned} \tag{5}$$

where $\Delta reuse\ rate_{i,j,t}$ is the change in reuse rate 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 reuse 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

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

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

shocks to the dealers or any other observable or unobservable shocks to dealers that may affect their willingness to reuse 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 (Ranaldo, Schaffner and Vasios, 2021). 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 reuse 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 it 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* indicates a significant positive relationship between the share of a bond purchased by the PSPP and changes in collateral reuse. This shows that market participants react to rising collateral scarcity by increasing the reuse rate. This finding is robust across all specifications (1) 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 0.89 indicates that a one percentage point purchase of the Eurosystem as a share of the total outstanding of a bond increases the collateral reuse rate by 0.89%.

We also find that the reuse rate is positively associated with increases in the amount outstanding. This is intuitive as more collateral becomes available for reuse through re-issuance. However, the effect is smaller compared to that of PSPP purchases. A one percent increase in the amount outstanding lowers the reuse rate only by 0.10 percentage points. This asymmetry is consistent with the findings of Infante and Saravay (2020) who also document a reuse sensitivity to central bank purchases that is five to ten times higher compared to that of issuances. When bonds are in high demand we also see an increase in the reuse rate. For "on the run" bonds we observe a statistically significant higher reuse rate. The coefficient for "cheapest to deliver" is positive but not statistically significant. In sum, our baseline regression shows that collateral reuse by dealers increases in response to scarcity induced by central bank purchases.

3.2 Intensive and extensive margin of collateral reuse adjustment

We next study the different channels through which dealers may adjust their collateral reuse. On the one hand, they can increase the rate at which they reuse already received collateral, as we have shown above. On the other hand, dealers can seek to borrow more collateral in the market in order to funnel it to prospective borrowers. We refer to the former as the intensive and to the latter as the extensive margin of collateral reuse. To study the two channels and their joint effect we run a similar regression as in Equation (5), using $\Delta \log(\textit{Incoming collateral})$ and $\Delta log(reuse)$ as dependent variables.

Table 3 reports the results of these regressions, using the most saturated fixed effect specification. Column (1) repeats the analysis of Table 2 with $\Delta \textit{Reuse rate}$ as dependent variable, serving as comparison. As can be seen from Column (2), dealers not only adjust collateral reuse at the intensive but also the extensive margin when a bond becomes scarce. The volume of incoming collateral increases by 0.11 percent for a purchase of 1% of the outstanding amount. 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 the incoming collateral for that bond. Column (3) looks at the joint effect, i.e. the changes in the overall amount of collateral reused. We find that dealers increase their reuse by 0.15 percentage points in response to an asset purchase that amounts to 1% of the bond's outstanding amount.

For robustness regarding the measurement of collateral reuse we consider the different reuse metrics introduced in Section 2, which represent an upper and lower bound. The results, which are provided in Table IA.2 of the Internet appendix, are virtually the same as those of our baseline regression in Table 3. Hence our results do not depend on the assumption that dealers proportionally use own assets and collateral received when posting collateral.

As discussed in Section 2, the majority of reused collateral of German dealers is domestic. In the subsequent analyses, we thus focus on German Bunds 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 the total amount outstanding increases the level of reuse of German collateral by about 0.22 percent and the reuse rate by 1.25 percentage points. Also for German collateral there is a positive association between asset purchases and incoming collateral, however the coefficient is not statistically significant with a p-value of 1.61.

3.3 Economic magnitude of the collateral reuse channel

We have shown that dealers react to scarcity-inducing purchases primarily via the intensive margin, that is by adjusting their reuse 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 reuse 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 as follows (FSB, 2017*a*)[8]:

$$\begin{aligned} \textit{effective amount} &= \textit{base amount} \times \sum_{n=0}^{\infty} \textit{reuse rate}^n \\ &= \frac{\textit{base amount}}{1 - \textit{reuse rate}} . \end{aligned} \tag{6}$$

The intuition behind Equation (6) is the following. Suppose bank A uses a certain amount of a bond as collateral in a 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 and reuses 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, the one received by bank B and the amount received by bank C. As this series of reuses

[8] We thank Toomas Laarits for this suggestion.

goes to infinity, it can be approximated as a geometric sum, yielding the second identity of Equation (6), see also Bottazzi et al. (2012).

Given our estimated reuse rates, what would this imply for the total collateral available? To answer this question, we calibrate Equation (6) to our data. We assume a reuse rate of 62.1%, which is the median value in the dealer-security panel used in our previous estimation. Hence, at the given value of reuse rate one unit of a bond supports 2.64 times as much collateral in the market.

Given a reduction in the supply of collateral, how do dealers need to adjust their reuse 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 reuse rate in our example needs to be 62.5%, i.e. an increase by 0.4 percentage points. This is considerably lower than the estimated coefficient in Table 3, Column (2). An asset purchase of 1% of the amount outstanding increases the reuse rate by 0.89 percentage points. This conclusion is robust at different levels of reuse and taking into account haircuts, see Table IA.3 in the Internet appendix. Hence, at first sight dealers seem to overcompensate the collateral reduction through collateral reuse.

One potential explanation for this discrepancy is that a purchase of one 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. Hence a purchase of one percent of the amount outstanding may actually correspond to a reduction in the effective amount of collateral available to reuse that is about two to three times as large. Consistent with this notion, Koijen, Koulischer, Nguyen and Yogo (2020) find that euro area banks, which generally supply their holdings as collateral, are the second largest net seller of euro area government bonds (after foreign investors). 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), increased their holdings over the same period.[9]

3.4 Substitutability of collateral

So far we have shown that dealers react to scarcity in one bond by increasing reuse in the same bond. In principle, dealers could substitute scarce bonds by other bonds with similar characteristics. Studying asset purchases of the Federal Reserve, D'Amico et al. (2018) find only limited substitutability of closely related bonds in the market for specific collateral. In the European market for safe assets, dealers can also substitute across bonds of similar maturity and rating but different issuer country. However, to the extent that there is fragmentation in the market for collateral, such substitutability might be hampered (Schaffner et al., 2019).

To study dealers' substitution of collateral, we include two additional explanatory variables in our regression. First, we measure purchases in bonds with similar maturity of different issuer countries which have the same broad rating group (AAA, AA, ...). Second, we refine the first measure by looking at purchases in bonds of different countries which have the same rating notch (AAA, AA+, AA, AA-, ...). A positive regression coefficient for these measures implies that dealers react to scarcity in one bond by increasing reuse in similar bonds.

Table 4 shows the results. Importantly, the regressions include both dealer×time and dealer×bond fixed effects. Since the substitutability measures are defined at the country-time-maturity level we cannot include maturity bucket-country-time fixed effects as before. In Column (1) we study substitutability within a broad rating group, and in Column (2) within the narrower rating notch. While we find no significant substitution

[9] Another explanation could be that reuse chains are not infinitely long. That said, if we assume that each unit of collateral is reused 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 2.48 (2.62) in the example above. When we assume that collateral is reused only about twice the calculated estimate is comparable to the empirically observed value. However we deem such short chains unlikely.

effects in the broad category, we observe that scarcity in bonds of other countries with the same rating notch has a significant positive effect on reuse. For an average purchase rate corresponding to one percent of the amount outstanding in these securities, the reuse rate increases by one percentage point.

German Bunds are widely considered as *the* Euro-denominated safe asset. It is thus a natural question whether the collateral reuse activity we have documented extends to other safe assets in the euro area. We therefore distinguish between reuse in non-German sovereign bonds and German Bunds. In Column (3) we consider the effect of asset purchases of bonds with the same rating notch and maturity bucket, including purchases of German bonds, on the reuse of bonds issued by non-German European sovereigns. We find that substitutability is more pronounced in this subsample: the coefficient estimate almost doubles from column (2) to (3). Column (4) considers the effect of asset purchases in AAA-rated non-German sovereign bonds (such as Finnish or Dutch securities) on the reuse of German Bunds. Here we find no substitutability. Hence, the reuse activity in German sovereign bonds is insensitive to purchases in other AAA rated sovereigns. These results show that dealers substitute between bonds in their collateral management. However, this substitutability is asymmetric, in line with prior evidence for fragmentation in the euro area repo market (Brand et al., 2019; Cœuré, 2019; Schaffner et al., 2019).

4 Collateral reuse and bond scarcity

We next explore how collateral reuse 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 e.g. due to increased demand (Duffie, 1996). The specialness spread thus measures the cost of borrowing a specific collateral in the repo market.

Dealers can increase supply in the repo market by reusing the incoming collateral from other transactions. However, there is a binding constraint as dealers cannot post more collateral than they received or own and may additionally be restricted by haircuts or margin requirements. We therefore study how market participants' reaction to asset scarcity depends on their already reached level of collateral reuse in the specific securities.

In order to capture the impact of collateral reuse on bond scarcity, we require a good coverage of overall reuse activity. As shown in Figure 3, German banks are mostly using domestic collateral in their transactions. Government bonds of other countries are also used, but German bank market coverage is considerably lower in these bonds. Therefore, from here on, we focus on the reuse 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.[10]

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 approach of Arrata et al. (2020) and regress changes in the specific collateral repo rate $\Delta repo\ rate_{i,t}$ on our measures of reuse activity and a set of controls, including the lagged change in repo rates[11]:

$$\begin{aligned} \Delta repo\ rate_{i,t} &= \beta_0 + \beta_1 Purchase_{i,t} + \beta_2 Reuse_{i,t-1} + \beta_3 Purchase_{i,t} \times Reuse_{i,t-1} \\ &\quad + \gamma' Controls_{i,t} + \alpha_i + \alpha_{m,t} + \varepsilon_{i,t} \quad . \end{aligned} \tag{7}$$

[10]See Tables IA.4 and IA.5 in the Internet Appendix.

[11]In a dynamic panel model estimates can be biased, but this bias is decreasing with the length of the sample T (Nickell, 1981). Given the sample length of $T = 34$ in our application, the Nickell bias is negligible irrespective of the persistence of the endogenous variable (Phillips and Sul, 2007).

To account for the potential endogeneity between reuse and repo rates we interact PSPP purchases with the *lagged* level of collateral reuse. The intuition is as follows: it should be easier for market participants to expand their reuse activity in bonds with a low level of reuse, thus making repo rates less sensitive to purchase-induced scarcity. In contrast, dealers may not be able to compensate the reduced supply for bonds that are already heavily reused. We thus expect a negative coefficient on this interaction term. We consider two measures of reuse. First, we standardize collateral reuse by dividing the amount reused by outright ownership and take the logarithm, i.e. log(*Reuse*/*Outright ownership*). Second, we measure reuse activity via the *Reuse rate*. For comparability, both measures are demeaned and standardized to have unit variance. *Controls* accounts for lagged changes in the repo rate and, as above, 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 5 presents the estimation results. In Column (1) 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 one percent of the amount outstanding reduces the bond's repo rate by 1.05 basis points. Despite the fact that our estimation approach is monthly and our sample is restricted to German government bonds, the magnitude is similar to Arrata et al. (2020), who report a reduction of 0.78 basis points with regard to a one percent PSPP purchase.

In Columns (2) and (3) we include the interaction term related to the past level of collateral reuse. Crucially, for both measures of reuse the interaction term is significant, both in statistical and economic terms. A one standard deviation increase in the normalized reuse measure in Column (2) further lowers the special repo rate by more than half a basis point for each percent share of amount outstanding purchased. This corresponds to an increase by about one half with respect to the baseline sensitivity of repo rates to Eurosystem asset purchases. The effect for a similar increase in the reuse rate, shown in

Column (3), is even stronger, implying a -0.67 basis points additional reduction in the repo rate for each percent of amount outstanding purchased.

These results highlight the importance of collateral reuse in compensating asset scarcity. Repo rates are less sensitive to scarcity induced by asset purchases at low levels of reuse, and more so when reuse activity is high.

5 Collateral reuse and repo rate volatility

Market participants can contribute to dampening scarcity effects by more efficiently using their available collateral. Collateral reuse, 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 reuse activity manifests itself in higher volatility on the repo market.

We study the relation of repo market volatility and collateral reuse via the following regression model:

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

where the dependent variable $\log(\textit{repo rate volatility})_{i,t}$ is the logarithm of the realized volatility of the repo rate of bond i over the course of month t. As above, we account for the lagged level of collateral reuse using first the rescaled amount of collateral reused $\log(\textit{Reuse}/\textit{Outright ownership})$ and second the *Reuse rate*. 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. We control for the lagged level of volatility, the lagged yield and the log of the lagged total amount outstanding. Furthermore, we include dummy variables for on-the-run status and when a bond is the cheapest-to-deliver in futures contracts.

Table 6 reports the regression results of Equation (8). Columns (1) and (2) are our baseline regressions. Cheapest-to-deliver bonds exhibit higher volatility, while bonds with a larger amount outstanding are less volatile. 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 reuse, as we have shown above that dealers expand reuse when bonds become scarce. Hence, we expect these two variables to pick up some of the effects attributed to the collateral reuse 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. In Columns (3) - (6) we account for collateral reuse. We find that bonds with more reuse activity experience increased repo rate volatility in the next month. A one standard deviation increase in the amount reused scaled by outright ownership predicts an increase in repo rate volatility of 3%. Similarly, a one standard deviation increase in the reuse rate is associated with a 4% higher repo rate volatility in the next month. As expected, the coefficients are slightly smaller when controlling for the lagged repo rate, but remain statistically significant at the 10% and 5% level, respectively. In other words, high collateral reuse activity is associated with higher future repo market volatility.

In sum, while dealers' reuse of safe-asset collateral mitigates scarcity effects induced by central bank asset purchases, a high level of reuse is associated with more repo market volatility. This highlights the tradeoffs associated with collateral reuse. While reuse can help to absorb shocks by making more collateral available, high levels of reuse increase the interconnectedness of market participants and can thus lead to an amplification of shocks.

6 Conclusion

In this paper we document that dealer banks adjust to safe asset scarcity by making more efficient use of received collateral. In response to sovereign debt purchases by the

Eurosystem, dealers increase their collateral reuse activity. The increase in collateral reuse absorbs part of the supply reduction, which is reflected in a lower scarcity premium on the repo market following an asset purchase. But increasing collateral reuse also has a downside: high levels of collateral reuse 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 reuse, 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 resulting premia for safe assets. Market participants' endogenous response to safe asset scarcity through collateral reuse may result in an amplification of shocks and increased market volatility.

References

Aggarwal, R., Bai, J. and Laeven, L. (2020), 'Safe-asset shortages: Evidence from the european government bond lending market', *Journal of Financial and Quantitative Analysis* pp. 1–31.

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.

Cœuré, B. (2019), A tale of two money markets: fragmentation or concentration, *in* 'speech at the ECB workshop on money markets, monetary policy implementation and central bank balance sheets'.

Corradin, S. and Maddaloni, A. (2020), 'The importance of being special: repo markets during the crisis', *Journal of Financial Economics* **137**(2), 392–429.

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', *ECB Working Paper Series No 2052* .

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. (2020), 'The run on repo and the Fed's response', *Journal of Financial Stability* **48**, 100744.

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. (2019), 'Liquidity windfalls: The consequences of repo rehypothecation', *Journal of Financial Economics* **133**(1), 42–63.

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* .

Nickell, S. (1981), 'Biases in dynamic models with fixed effects', *Econometrica* pp. 1417–1426.

Phillips, P. C. and Sul, D. (2007), 'Bias in dynamic panel estimation with fixed effects, incidental trends and cross section dependence', *Journal of Econometrics* **137**(1), 162–188.

Ranaldo, A., Schaffner, P. and Vasios, M. (2021), 'Regulatory effects on short-term interest rates', *Journal of Financial Economics* **141**(2), 750–770.

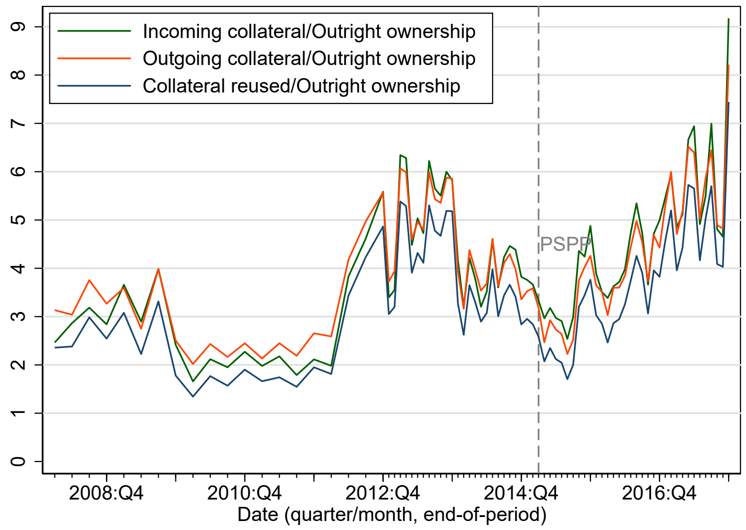
Schaffner, P., Ranaldo, A. and Tsatsaronis, K. (2019), 'Euro repo market functioning: collateral is king', *BIS Quarterly Review, December* .

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) Reuse Rate

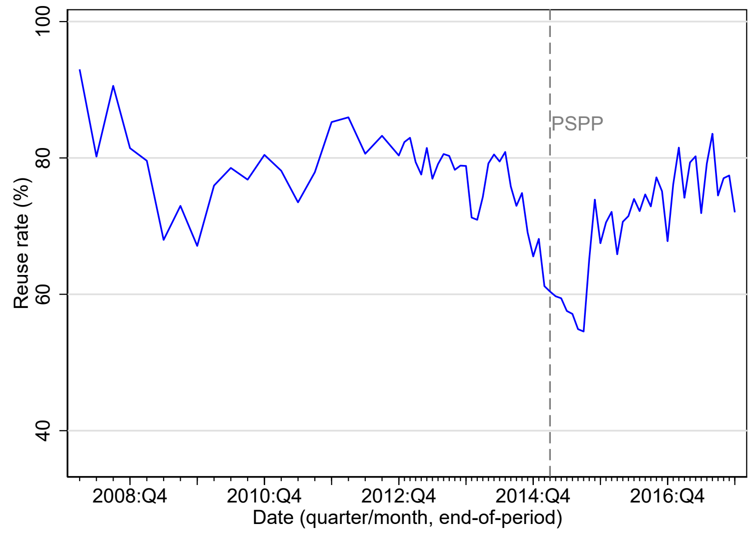


Figure 1: Collateral reuse over time

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

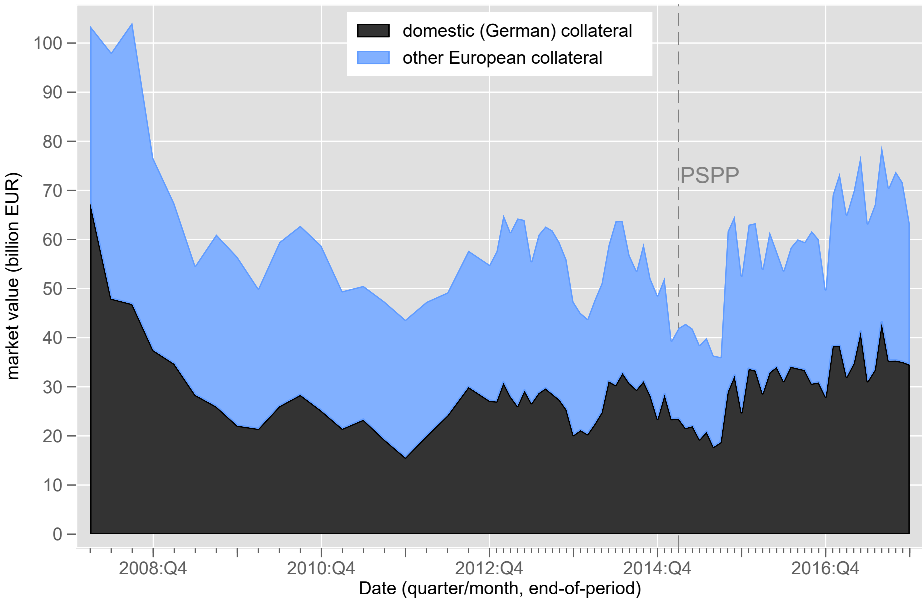


Figure 2: Collateral Reused: Domestic vs. foreign
This figure shows the market value of collateral reused for domestic (i.e. German) collateral and collateral by other European countries in our sample. We consider European sovereign bonds with remaining maturity between 1 and 30 years. The sample period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

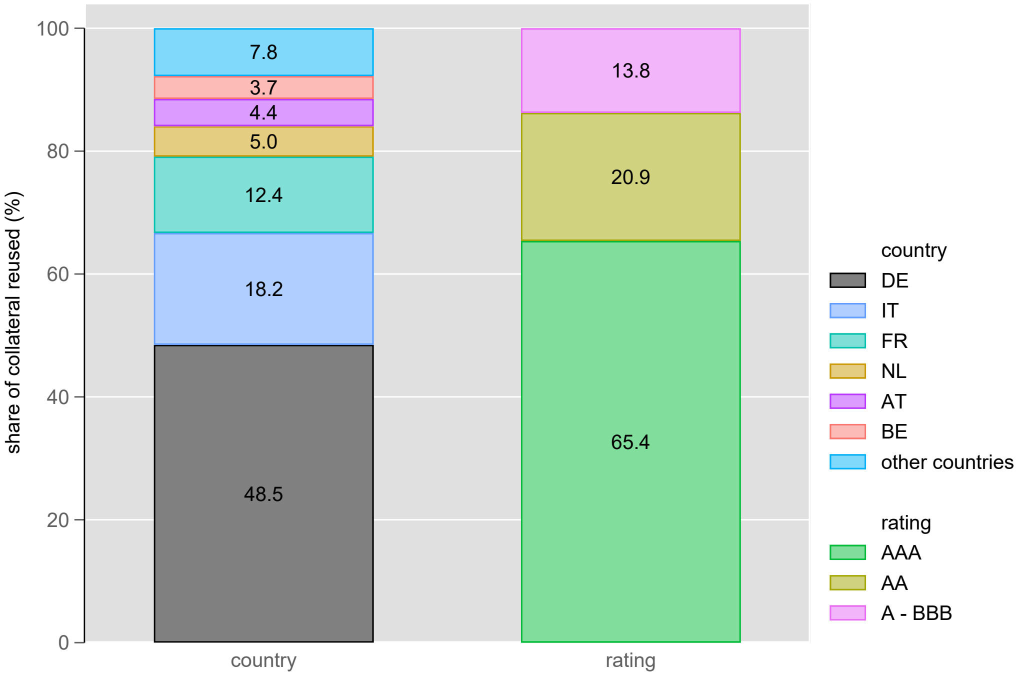


Figure 3: Collateral Reused by Issuer Country and Rating
This figure shows the overall share of collateral reused, computed as the time-series average, in our sample, by issuer country (left column) and by issuer rating (right column). The group *other countries* includes Spain, Finland, Greece, Ireland, 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.

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 reuse rate (ΔReuse Rate$_t$), logarithmic amount of incoming collateral ($\Delta \log$(Incoming collateral)$_t$) and logarithmic amount reused (Δlog Reuse$_t$). 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)$_t$).

		Std.	Percentiles			
Variable	Mean	dev.	25th	50th	75th	N
Panel A: Reuse variables						
ΔReuse Rate$_t$	0.18	44.62	-3.16	0.00	3.81	35,932
Δ log(Incoming collateral)$_t$	0.04	7.25	-0.06	0.00	0.03	35,932
Δlog Reuse$_t$	0.04	8.52	-0.25	0.00	0.26	35,932
Panel B: Repo rate variables						
ΔRepo Rate$_t$	-2.07	29.20	-6.98	-1.47	3.22	1,681
log(Repo Rate Volatility)$_t$	-3.00	1.15	-3.81	-3.19	-2.44	1,688

Table 2:
Asset purchases and collateral reuse

The table reports the results of a regression of changes in reuse rate (ΔReuse Rate$_t$) 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: ΔReuse Rate$_t$				
Asset purchases$_t$ (%)	0.60**	0.57**	0.69**	0.73***	0.89***
	(2.29)	(2.15)	(2.46)	(2.65)	(2.80)
Δ Amount outstanding$_t$	-0.11**	-0.11**	-0.10*	-0.09*	-0.10*
	(-2.26)	(-2.20)	(-1.84)	(-1.74)	(-1.77)
Dummy: On the run$_t$	4.89***	4.54**	5.21**	5.24***	5.90***
	(2.70)	(2.44)	(2.56)	(2.63)	(2.85)
Dummy: Cheapest-to-deliver$_t$	0.12	0.06	0.12	0.26	0.48
	(0.08)	(0.04)	(0.08)	(0.17)	(0.30)
Constant	-0.45	-0.39	-0.51	-0.56*	-0.73**
	(-1.40)	(-1.22)	(-1.54)	(-1.72)	(-2.12)
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	.01534	.09811	.1084	.1216	.1484
N	35,927	35,747	35,093	35,093	35,026

Table 3:
Asset purchases and collateral reuse: 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. In specifications (1) and (4) the dependent variable is changes in reuse rate (ΔReuse Rate$_t$), and in specifications (2) and (5) changes in the logarithmic amount of incoming collateral ($\Delta \log(\text{Incoming})_t$). The dependent variable in specifications (3) and (6) is changes in logarithmic amount of collateral reused (Δlog Reuse$_t$), where specification (1) repeats specification (5) in Table 2. 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:	ΔReuse Rate$_t$	$\Delta \log(\text{Incoming})_t$	$\Delta \log(\text{Reuse Amt.})_t$	ΔReuse Rate$_t$	$\Delta \log(\text{Incoming})_t$	$\Delta \log(\text{Reuse Amt.})_t$
Asset purchases$_t$ (%)	0.89***	0.11**	0.15**	1.25**	0.14	0.22**
	(2.80)	(1.98)	(2.43)	(2.52)	(1.61)	(2.42)
Δ Amount outstanding$_t$	-0.10*	0.02*	0.00	0.05	0.04***	0.03*
	(-1.77)	(1.82)	(0.04)	(0.60)	(2.86)	(1.65)
Dummy: On the run$_t$	5.90***	0.64*	0.78**	5.21	-0.07	0.45
	(2.85)	(1.78)	(1.97)	(1.27)	(-0.10)	(0.59)
Dummy: Cheapest-to-deliver$_t$	0.48	0.09	0.07	-0.86	-0.07	-0.12
	(0.30)	(0.32)	(0.22)	(-0.42)	(-0.22)	(-0.33)
Constant	-0.73**	-0.10*	-0.13*	-1.10	-0.15	-0.20*
	(-2.12)	(-1.75)	(-1.91)	(-1.59)	(-1.39)	(-1.65)
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	.1484	.1073	.1382	.1698	.1128	.1681
N	35,026	35,026	35,026	10,054	10,054	10,054

Table 4:
Asset purchases and collateral reuse: Cross-country Spillovers

The table reports the results of a regression of changes in reuse rate (ΔReuse rate$_t$) on asset purchases in a dealer-bond-time panel at monthly frequency. The regression model is outlined in Equation (5) and in Section 3.4. In addition to the analysis of Table 3 we account also for the average level of purchases of bonds with the same rating and maturity bucket, excluding the country of the bond of interest. In specification (1) we consider bonds within the same rating group (e.g. AA) and in specifications (2) - (4) within the same rating notch (e.g. AA+). The sample consists of European sovereign bonds in specifications (1) - (2). In specification (3) we consider the effect of asset purchases of bonds with the same rating notch and maturity-bucket, including purchases of German bonds, on the reuse of bonds issued by non-German European sovereigns. Specification (4) considers the effect of asset purchases in AAA-rated non-German sovereign bonds on the reuse of German Bunds. 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)
Issuer country of reused collateral:	all		not Germany	Germany
	Dependent variable: ΔReuse Rate$_t$			
Asset purchases$_t$ (%)	0.64**	0.59**	0.78**	0.76*
	(2.25)	(2.09)	(2.10)	(1.70)
Asset purchases$_t$ (same rating group and maturity bucket, %)	0.47			
	(0.76)			
Asset purchases$_t$ (same rating notch and maturity bucket, %)		1.01**	1.81***	-0.76
		(2.01)	(3.11)	(-0.72)
Δ Amount outstanding$_t$	-0.10*	-0.09*	-0.21***	0.01
	(-1.80)	(-1.77)	(-2.86)	(0.10)
Dummy: On the run$_t$	5.20**	5.23**	4.81**	6.13
	(2.56)	(2.57)	(2.08)	(1.49)
Dummy: Cheapest-to-deliver$_t$	0.12	0.10	2.20	-0.73
	(0.08)	(0.07)	(0.92)	(-0.37)
Constant	-0.89	-1.25**	-1.89***	0.08
	(-1.48)	(-2.52)	(-3.23)	(0.08)
Fixed effects:				
dealer×time	yes	yes	yes	yes
dealer×bond	yes	yes	yes	yes
R^2	.1084	.1085	.1174	.1569
N	35,093	35,093	24,961	10,063

Table 5:
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 specification (2) we additionally account for the lagged level of collateral reuse normalized by outright ownership in the same bond, and its interaction with asset purchases, and idem in specification (3) for the lagged reuse rate. Both reuse measures are standardized to have mean zero and unit variance. 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 2017. 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)
	Dependent variable: ΔRepo Rate$_t$		
Asset purchases$_t$ (%)	-1.05***	-1.16***	-1.00***
	(-3.19)	(-3.64)	(-3.20)
ΔRepo Rate$_{t-1}$	-0.44***	-0.45***	-0.44***
	(-22.34)	(-23.96)	(-21.03)
Δ Amount outstanding$_t$	0.64*	0.66*	0.65*
	(1.95)	(1.79)	(1.97)
Dummy: On-the-run$_t$	-24.30*	-25.38	-25.07*
	(-1.68)	(-1.64)	(-1.71)
Dummy: Cheapest-to-deliver$_t$	0.10	0.22	0.00
	(0.12)	(0.27)	(0.00)
log(*Reuse/Outright ownership*)$_{i,t-1}$		1.13***	
		(3.37)	
Asset purchases$_t$ (%) × log(*Reuse/Outright ownership*)$_{i,t-1}$		-0.52**	
		(-2.50)	
Reuse rate$_{t-1}$			1.47***
			(2.73)
Asset purchases$_t$ (%) × *Reuse rate*$_{t-1}$			-0.67*
			(-1.87)
Constant	-1.68***	-1.57***	-1.68***
	(-3.83)	(-3.60)	(-4.00)
Fixed effects:			
bond	yes	yes	yes
maturity bucket×time	yes	yes	yes
R^2	.8511	.8518	.8523
N	1,671	1,634	1,671

Table 6:
Collateral reuse 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. In specifications (3) and (4) we additionally account for the lagged level of collateral reuse normalized by outright ownership in the same bond, and in specifications (5) and (6) for the lagged reuse rate. Both measures are standardized to have unit variance. We control for lagged volatility, lagged yield, changes in the amount outstanding and on-the-run and cheapest-to-deliver status. In specifications (2), (4) and (6) 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. 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)	(5)	(6)
	Dependent variable: log(Repo Rate Volatility)$_t$					
log(Repo Rate Volatility)$_{t-1}$	0.16***	0.12***	0.14***	0.11***	0.15***	0.12***
	(5.01)	(3.88)	(4.33)	(3.31)	(4.73)	(3.71)
Yield$_{t-1}$ (%)	-0.00	0.00	0.00	0.01	-0.01	0.00
	(-0.10)	(0.08)	(0.07)	(0.20)	(-0.12)	(0.02)
Amount outstanding$_{t-1}$ (log)	-0.42***	-0.38**	-0.44***	-0.40**	-0.42***	-0.39**
	(-2.65)	(-2.37)	(-2.75)	(-2.47)	(-2.73)	(-2.46)
Dummy: on-the-run$_t$	0.03	0.10	0.07	0.13	0.04	0.10
	(0.33)	(0.97)	(0.70)	(1.21)	(0.39)	(0.97)
Dummy: Cheapest-to-deliver$_t$	0.17***	0.15***	0.18***	0.15***	0.16**	0.14**
	(2.85)	(2.80)	(3.20)	(3.17)	(2.53)	(2.56)
Overall share purchased$_{t-1}$		-0.00		-0.00		-0.00
		(-0.63)		(-0.74)		(-0.51)
Repo rate$_{t-1}$		-0.72***		-0.72***		-0.70***
		(-5.02)		(-5.03)		(-4.91)
log(*Reuse/Outright ownership*)$_{i,t-1}$			0.03**	0.02*		
			(2.33)	(1.70)		
Reuse rate$_{t-1}$					0.04**	0.03**
					(2.63)	(2.02)
Constant	7.28*	5.94	7.74**	6.41*	7.43**	6.17*
	(1.98)	(1.61)	(2.08)	(1.72)	(2.05)	(1.69)
Fixed effects:						
bond	yes	yes	yes	yes	yes	yes
time	yes	yes	yes	yes	yes	yes
R^2	.8658	.8702	.8652	.8695	.8667	.8706
N	1,692	1,692	1,652	1,652	1,691	1,691

Internet Appendix accompanying
"Safe asset shortage and collateral reuse"

Table IA.1:
Descriptive statistics: reuse rates

This table shows summary statistics and correlations of collateral reuse rates, employing the three different measures for collateral reuse 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.

Row	Variable	Mean	Std. dev.	Percentiles 25th	50th	75th	Correlation (1)	(2)	(3)
(1)	$\textit{reuse rate}^{lower}$ (%)	44.1	45.7	0.0	22.3	98.7	1		
(2)	$\textit{reuse rate}^{prop.}$ (%)	46.2	45.4	0.0	41.9	98.8	0.98	1	
(3)	$\textit{reuse rate}^{upper}$ (%)	48.5	46.6	0.0	50.0	100.0	0.93	0.98	1

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

This table provides a robustness check to the analysis of Table 3 using the upper- and lower-bound reuse as dependent variable in the regression instead. The dependent variable is changes in reuse rate (ΔReuse Rate$_t$) in specifications (1) - (3), and changes in logarithmic amount of collateral reused (Δlog Reuse$_t$) 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 reuse 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:	ΔReuse Rate$_t$			Δ log(Reuse Amt.)$_t$		
Reuse computation:	Lower bound	Prop. measure	Upper bound	Lower bound	Prop. measure	Upper bound
Asset purchases$_t$ (%)	0.82***	0.89***	0.94***	0.15**	0.15**	0.15**
	(2.60)	(2.80)	(2.90)	(2.39)	(2.43)	(2.41)
Δ Amount outstanding$_t$	-0.10*	-0.10*	-0.08	-0.01	0.00	0.00
	(-1.93)	(-1.77)	(-1.51)	(-0.51)	(0.04)	(0.11)
Dummy: On the run$_t$	5.65***	5.90***	5.84***	0.78*	0.78**	0.77*
	(2.74)	(2.85)	(2.74)	(1.95)	(1.97)	(1.94)
Dummy: Cheapest-to-deliver$_t$	0.52	0.48	0.52	0.14	0.07	0.06
	(0.31)	(0.30)	(0.30)	(0.47)	(0.22)	(0.19)
Constant	-0.63*	-0.73**	-0.81**	-0.11*	-0.13*	-0.13*
	(-1.83)	(-2.12)	(-2.29)	(-1.71)	(-1.91)	(-1.91)
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	.1442	.1484	.1498	.1308	.1382	.1383
N	35,026	35,026	35,026	35,026	35,026	35,026

Table IA.3:
Adjustment to reuse rates necessary to compensate supply reductions.
This table provides a robustness check to the analysis in Section 3.3 using a wide set of potential parameters. Taking into account a haircut HC that is applied each time that collateral is (re-)used, Equation (6)) becomes $\textit{effective amount} = \textit{base amount} \times (1 - HC) \times \sum_{n=0}^{\infty} (\textit{reuse rate} \times (1 - HC))^n = \textit{base amount} \times \frac{(1-HC)}{1-\textit{reuse rate}\times(1-HC)}$. Specifically we compute the reuse rate *reuse rate′* that is necessary to compensate for a reduction by one percent in collateral supply (*base amount*) given the initial *reuse rate* and haircut. Δ*reuse rate* gives the corresponding increase in the reuse rate in percentage points. The mean (median) haircut for our sample as reported in the ECB's eligible assets database is 2% (3.3%).

reuse rate (%)	haircut (%)	*reuse rate′* (%)	Δ*reuse rate* (%)
20.00	0.00	20.80	0.80
40.00	0.00	40.60	0.60
60.00	0.00	60.40	0.40
62.10	0.00	62.48	0.38
80.00	0.00	80.20	0.20
90.00	0.00	90.10	0.10
95.00	0.00	95.05	0.05
99.00	0.00	99.01	0.01
20.00	3.00	20.83	0.83
40.00	3.00	40.63	0.63
60.00	3.00	60.43	0.43
62.10	3.00	62.51	0.41
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
20.00	5.00	20.85	0.85
40.00	5.00	40.65	0.65
60.00	5.00	60.45	0.45
62.10	5.00	62.53	0.43
80.00	5.00	80.25	0.25
90.00	5.00	90.15	0.15
95.00	5.00	95.10	0.10
99.00	5.00	99.06	0.06

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 5 using a more general universe of bonds. We consider domestic and non-domestic sovereign bonds for which we observe a reuse activity comparably to domestic collateral. Specifically, we standardize the aggregate amount of collateral reuse 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 specification (2) we additionally account for the lagged level of collateral reuse normalized by outright ownership in the same bond, and its interaction with asset purchases, and idem in specification (3) for the lagged reuse rate. Both reuse measures are standardized to have unit variance. 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 2017. 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)
	Dependent variable: ΔRepo Rate$_t$		
Asset purchases$_t$ (%)	-0.94***	-1.01***	-0.88***
	(-2.83)	(-3.00)	(-2.95)
ΔRepo Rate$_{t-1}$	-0.44***	-0.45***	-0.44***
	(-20.91)	(-22.13)	(-19.25)
Δ Amount outstanding$_t$	0.40*	0.39	0.40*
	(1.79)	(1.62)	(1.75)
Dummy: On-the-run$_t$	-15.14	-15.38	-15.25
	(-1.46)	(-1.44)	(-1.43)
Dummy: Cheapest-to-deliver$_t$	-0.10	-0.19	-0.26
	(-0.12)	(-0.24)	(-0.29)
log(*Reuse*/*Outright ownership*)$_{i,t-1}$		1.35***	
		(2.85)	
Asset purchases$_t$ (%) × log(*Reuse*/*Outright ownership*)$_{i,t-1}$		-0.61**	
		(-2.31)	
Reuse rate$_{t-1}$			1.23**
			(2.43)
Asset purchases$_t$ (%) × *Reuse rate*$_{t-1}$			-0.47
			(-1.25)
Constant	-1.56***	-1.54***	-1.57***
	(-3.26)	(-3.19)	(-3.47)
Fixed effects:			
bond	yes	yes	yes
maturity bucket×time	yes	yes	yes
R^2	.8437	.8458	.8444
N	1,775	1,731	1,775

Table IA.5:
Collateral reuse and repo market volatility
Robustness check: Extended sample of bonds.

This table provides a robustness check to the analysis of Table 6 using a more general universe of bonds. We consider domestic and non-domestic sovereign bonds for which we observe a reuse activity comparably to domestic collateral. Specifically, we standardize the aggregate amount of collateral reuse 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 (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. In specifications (3) and (4) we additionally account for the lagged level of collateral reuse normalized by outright ownership in the same bond, and in specifications (5) and (6) for the lagged reuse rate. Both measures are standardized to have unit variance. We account also for lagged volatility, changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status, and in specifications (2), (4) and (6) 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 remaining maturity of all bonds is between 1 and 30 years. The sample period is March 2015 - December 2017. 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)	(5)	(6)
	Dependent variable: log(Repo Rate Volatility)$_t$					
log(Repo Rate Volatility)$_{t-1}$	0.19***	0.16***	0.17***	0.13***	0.18***	0.14***
	(6.88)	(5.67)	(4.98)	(3.87)	(5.63)	(4.49)
Yield$_{t-1}$ (%)	-0.03	-0.03	-0.01	-0.00	-0.01	-0.01
	(-0.55)	(-0.54)	(-0.18)	(-0.11)	(-0.24)	(-0.14)
Amount outstanding$_{t-1}$ (log)	-0.36***	-0.33***	-0.35**	-0.32**	-0.32**	-0.29**
	(-2.70)	(-2.71)	(-2.40)	(-2.31)	(-2.27)	(-2.16)
Dummy: on-the-run$_t$	0.01	0.05	0.05	0.10	0.03	0.08
	(0.08)	(0.60)	(0.54)	(0.99)	(0.36)	(0.86)
Dummy: Cheapest-to-deliver$_t$	0.13**	0.10*	0.13**	0.11**	0.12*	0.10*
	(2.06)	(1.79)	(2.36)	(2.12)	(1.92)	(1.76)
Overall share purchased$_{t-1}$		-0.01***		-0.01**		-0.01**
		(-2.84)		(-2.35)		(-2.21)
Repo rate$_{t-1}$		-0.79***		-0.76***		-0.76***
		(-5.37)		(-5.13)		(-5.14)
log($Reuse/Outright\ ownership$)$_{i,t-1}$			0.04**	0.03*		
			(2.51)	(1.71)		
Reuse rate$_{t-1}$					0.02	0.01
					(1.44)	(0.63)
Constant	6.00*	4.90*	5.58	4.45	5.07	3.97
	(1.92)	(1.73)	(1.66)	(1.41)	(1.53)	(1.26)
Fixed effects:						
bond	yes	yes	yes	yes	yes	yes
time	yes	yes	yes	yes	yes	yes
R^2	.8725	.884	.8796	.8846	.8788	.8836
N	2,082	2,015	1,742	1,742	1,788	1,788