DISCUSSION PAPER SERIES

DP16439
(v. 3)

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FINANCIAL ECONOMICS

ISSN 0265-8003

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Discussion Paper DP16439
First Published 27 June 2022
This Revision 28 August 2024

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Quantitative easing contributes to safe asset scarcity and repo market specialness. We show that banks respond to scarcity induced by Eurosystem bond purchases by increasing their reuse of these bonds as collateral. While reuse is low, additional reuse dampens scarcity effects. However, repo rates become increasingly sensitive to asset purchases when reuse is high. Elevated reuse also impairs market functioning: it leads to more failures to deliver specific bonds, a higher volatility of repo rates and more pronounced mispricing in the cash bond market. Our results highlight a trade-off between the shock absorption and shock amplification effects of collateral reuse.

JEL Classification: E4, E5, G1, G2

Keywords: Safe assets, Government bonds, Collateral reuse, Rehypothecation, Repo market, Securities lending

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Acknowledgements
This paper supersedes an earlier paper entitled “Safe asset shortage and collateral reuse”. 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. We are grateful to LCH RepoClear for the provision of delivery fails data. This paper represents the authors’ personal opinions and does not necessarily reflect the views of the Deutsche Bundesbank, its staff, or the Eurosystem.

Safe asset scarcity, collateral reuse, and market functioning*

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August 24, 2024

Abstract

Quantitative easing contributes to safe asset scarcity and repo market specialness. We show that banks respond to scarcity induced by Eurosystem bond purchases by increasing their reuse of these bonds as collateral. While reuse is low, additional reuse dampens scarcity effects. However, repo rates become increasingly sensitive to asset purchases when reuse is high. Elevated reuse also impairs market functioning: it leads to more failures to deliver specific bonds, a higher volatility of repo rates and more pronounced mispricing in the cash bond market. Our results highlight a trade-off between the shock absorption and shock amplification effects of collateral reuse.

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1 Introduction

Safe assets play an important role in the economy: they store value over time and serve as collateral in financial transactions. However, an increasing global demand for high-quality assets has been facing a declining pool of issuers in recent years, raising concerns about a shortage of safe assets. Large-scale purchases of sovereign debt by central banks have further contributed to a scarcity of high-quality collateral. Yet, the availability of safe assets as collateral does not only depend on the issued volume net of central bank holdings. Market participants can adjust to scarcity by reusing collateral more efficiently. In this paper, we use a unique granular dataset to study banks' reuse of collateral and its impact on bond market functioning in response to 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 ('repo') or earn a fee in a securities lending transaction. The collateral receiver, in turn, can reuse the security in another transaction, for example in a short-sale or in another repo. 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 effective 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).

Safe asset scarcity gives rise to repo market specialness. A bond is referred to trade "on special" in the repo market when the specific repo rate for that bond is lower than the rate for general collateral. The specialness spread, the difference between the repo rate for specific and general collateral, thus measures the extra cost of borrowing a specific security in the repo market. In a seminal paper, Duffie (1996) studies the drivers of repo market specialness. In his model, specialness spreads are increasing in the demand for short positions as well as the degree to which owners of the security are restricted from supplying it as collateral. According to Duffie (1996), legal or institutional barriers can inhibit the supply. He summarizes these restrictions with a single transaction cost parameter. While he doesn't explicitly consider reuse, collateral reuse would increase the overall availability of collateral in the market (Gottardi, Maurin and Monnet, 2019).

In this paper, we empirically document that the prevailing degree of collateral reuse is key to understanding the impact of safe asset scarcity on specialness spreads. We make the following contributions. First, we document that banks substantially increase their reuse in response to scarcity induced by central bank purchases. Second, we show that this reuse can mitigate scarcity premia. Importantly, though, we highlight a nonlinearity: while reuse is low, additional reuse dampens scarcity effects. On the flipside, repo rates become increasingly sensitive to asset purchases when reuse is already high. Finally, we show that at elevated levels of reuse, additional reuse is associated with a deterioration of government bond market functioning: it leads to a higher prevalence of failures to deliver in the repo market, an increased volatility of repo rates, and larger mispricing in the secondary cash bond market.

The 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 typically 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 portfolios at the security level 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 banks' collateral positions.

Specifically, we exploit a unique feature of the Bundesbank's Securities Holdings Statistics (SHS), which provides bond-level information on the amount of collateral received and posted in securities lending and repo transactions for each security for all German dealer banks.

Central bank purchases of government bonds provide a useful laboratory to study the effects of safe asset scarcity on collateral reuse and its implications for bond market functioning. Under the Public Sector Purchase Programme (PSPP), the Eurosystem bought more than EUR 2.5 trillion of member countries' sovereign debt between March 2015 and May 2022. These purchases corresponded to almost 30 percent of the total amount of euro area government debt outstanding and thus represented a significant reduction of collateral available to market participants. While the overall purchase amounts for different asset classes were published by the Eurosystem, the specific purchase amounts of individual securities that we observe were unknown to market participants. This allows us to study how an exogenous reduction in available collateral affects dealers' reuse activity and what this implies for market functioning. In our main analysis, we focus on the security-level reuse of German federal government bonds (Bunds), which is the collateral most commonly used by German dealer banks. We show robustness of our results for a larger pool of euro area sovereign debt securities.

The rate at which dealers reuse incoming collateral is high, fluctuating between 60% and more than 95% in our sample period which covers the years 2008 through 2017. Notably, the reuse rate increased markedly after the start of Eurosystem asset purchases. The amount of collateral reused is also substantial relative to the outright ownership in these bonds, increasing from two times dealers' own holdings before the start of the PSPP to more than 25 times at the end of the sample.

Using proprietary security-level information on PSPP purchases of German government bonds, 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 0.13% in the same month. This increase is driven by two channels. On the one hand, banks increase the rate at which they reuse collateral that they already have available by 1.63 percentage points. On the other hand, they source 0.10% more collateral from other market participants for reuse.

To what degree does banks' endogenous adjustment of collateral reuse mitigate safe asset scarcity? In line with the estimates in Arrata, Nguyen, Rahmouni-Rousseau and Vari (2020), we find that an asset purchase of 1% of the amount outstanding reduces Bunds' specific collateral repo rates by about one basis point, thus making it more costly to borrow these securities. While the previous literature had documented a link between central bank purchases and scarcity premia, we show that banks mitigate this scarcity by actively increasing collateral reuse. However, their ability to do so crucially depends on the prevailing level of reuse in a given bond: higher reuse activity substantially raises the sensitivity of the repo rate to asset purchases. These results highlight the importance of collateral reuse for mitigating or amplifying 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 raise it further is limited.

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 (Brumm, Grill, Kubler and Schmedders, 2023; FSB, 2017*b*). Moreover, extended reuse may result in a concentration of collateral markets and thus contribute to fragility of dealer banks' balance sheets (Infante and Vardoulakis, 2021). We assess the empirical relevance of these effects by studying the link between reuse and government bond market functioning.

Controlling for various demand and supply factors, we find that higher reuse rates are associated with substantially more frequent failures to deliver specific bonds and with strongly elevated repo rate volatility. This effect is particularly pronounced for bonds that trade on special in the repo market. The link between reuse and future repo market fails and volatility is non-linear, however. While there is no discernable relation for reuse rates below 60%, there is a strong positive link above that threshold. Combined, these findings highlight an important trade-off: collateral reuse can dampen scarcity effects when reuse is low, but amplify the side effects of scarcity on repo market functioning when the level of reuse is already high.

There is a close link between repo markets and government bond markets (Duffie, 1996; Jordan and Jordan, 1997). As a consequence, purchase-induced scarcity may result in mispricing in the secondary market for government bonds (D'Amico, Fan and Kitsul, 2018) and a disconnect between cash and futures markets (Pelizzon, Subrahmanyam and Tomio, 2024). We document this connection also in the case of PSPP purchases. However, we show that the impact of scarcity on pricing conditions in the secondary market is again tied to the level of reuse. For elevated reuse rates asset purchases significantly amplify the effect of scarcity premia on mispricing in the cash bond market, but this is not the case for reuse rates below that threshold.

In sum, we document that banks 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, repo and cash bond market functioning deteriorate with the degree of reuse activity. Hence, we highlight an important tradeoff: reuse can mitigate safe asset scarcity and help buffer shocks to net supply, but when it is already high collateral reuse may increase bond market fragility and act as a shockamplifier.

2 Related literature

Our paper relates to several strands of the literature. First and foremost, we contribute to the literature on safe asset shortages 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), among others, 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 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.

A growing theoretical literature explores the role of collateral reuse in financial markets, generally acknowledging 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, and Infante and Vardoulakis (2021) further show that such runs may generate fragility of dealer banks' balance sheets. In Andolfatto, Martin and Zhang (2017) reuse of collateral improves the efficient allocation of liquidity. Gottardi et al. (2019) show that repurchase agreements arise optimally as a borrowing instrument in competitive markets with limited commitment. Moreover, lenders reuse collateral in equilibrium, and the benefits of reuse are highest when assets are scarce. Consistently, we find that reuse rises when central bank asset purchases increase scarcity. In Brumm et al. (2023) 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 reuse and repo market quality.

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 (2021) 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. Going beyond this analysis, our dealer-security-level data additionally allow us to study the compensating effect of reuse on asset scarcity, as well as the implications of reuse activity on repo market fails, repo rate volatility and mispricing in the cash bond market. 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 (2021) 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.

[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.

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 et al., 2018; Jank and Moench, 2018; Brand, Ferrante and Hubert, 2019). In a recent study, Arrata et al. (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 fails-to-deliver. Our results document that the endogenous response of banks in using scarce collateral more effectively reduces the impact of such purchases on repo market specialness and on fails-to-deliver when reuse can easily be expanded, but that high levels of reuse amplify the sensitivity of specialness premia and fails to central bank asset purchases.

3 Measuring collateral reuse

According to the broad definition provided by 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 banks' 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 generally 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. Hence, for simplicity we assume that all incoming collateral is eligible for reuse.

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]

We focus on German sovereign bonds with a remaining maturity between 1 and 30 years and denominated in Euro. Before calculating our reuse measures we apply the following filters to the data. We employ a plausibility check to our data by omitting positions where the outgoing collateral exceeds the sum of amount owned outright and incoming collateral. Moreover, we restrict the sample to bonds that are actively used by German banks as collateral. Specifically, we drop observations where the outgoing collateral is zero both for the current and the previous period. In Appendix A we confirm our baseline findings for a larger sample of collateral issued by euro area member countries.

The lower panel of Figure 1 describes the dynamics of the aggregate incoming and outgoing collateral, normalized by the outright ownership across dealers and securities. Both ratios 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

[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).

outgoing collateral considerably exceed the dealers' outright holdings. Both metrics range between two and about 25 in our sample period. In particular, we see a strong increase in incoming and outgoing collateral after the introduction of the PSPP in March 2015. This suggests an increase in reuse activity in response to safe asset scarcity induced by central bank asset purchases.

Using banks' 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 intuition is as follows. Outgoing collateral can in principle originate from two sources: own assets or incoming collateral, fulfilling the following inequality: $Outgoing\ collateral_{ij} \leq Outright\ ownership_{ij} + Incoming\ collateral_{ij}$. The measure assumes proportional use of own assets and incoming collateral when posting collateral, which is captured by the first term of Equation (1). Two examples illustrate this. If incoming collateral is zero, then all outgoing collateral has to come from outright ownership and reuse for that bond is zero. If outright ownership is zero, on the contrary, then all outgoing collateral has to be sourced from incoming collateral and reuse for that security is 100%. For all values in between, reuse is proportional to the incoming collateral's share of total collateral available. This proportional use of collateral 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.[3] The upper panel of Figure 1 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.

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 bank in a specific security. It indicates how extensively the bank uses its collateral resources and therefore sometimes referred to as "collateral efficiency" (Kirk et al., 2014). When there is no incoming collateral we define $reuse\ rate_{i,j} := 0$. A substantial part of our empirical analysis relies on collateral reuse measured at the level of individual bonds. To this end, we compute the security-specific $reuse\ rate_i$ by aggregating for bond i the amount of incoming and reused collateral over all German dealer banks.

The lower panel of Figure 1 shows the aggregate reuse rate for German 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 rising sharply. Table 1

[3] 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, Ranaldo and Tsatsaronis, 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.

provides summary statistics for the different reuse measures as well as further variables of interest which we use in our regression analysis.

In Appendix B, we compute two alternative measures of reuse which represent an upper and lower bound for the proportional measure of collateral reuse activity, respectively. We find that the three measures imply very similar reuse rates.[4] In what follows, we thus focus on the proportional measure of collateral reuse since it most closely resembles actual market practices. As a robustness check, we repeat our main analyses using the upper and lower bound approach in the Appendix, obtaining very similar results.

4 How collateral reuse responds to changes in safe asset scarcity

In this section, we empirically analyze how banks respond to changes in collateral scarcity. We first investigate how they adjust their overall reuse of collateral when it becomes more scarce as a result of central bank purchases. Moreover, we distinguish between the intensive and extensive margins of this adjustment, captured by changes in the reuse rate and the amount of incoming collateral.

4.1 The effects of asset scarcity on collateral reuse

We start by analyzing how market participants adjust their reuse of collateral to a shock in collateral supply. We exploit the Eurosystem's purchases of government bonds via its Public Sector Purchase Program (PSPP) as a measure of variation in safe asset shortage. 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

[4]See Table IA.2. 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.

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

Our approach resembles that of the literature which studies the effects of central banks' asset purchases on bond yields (De Santis and Holm-Hadulla, 2020; Schlepper, Hofer, Riordan and Schrimpf, 2020) 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:

$$\begin{aligned}\Delta \log(\text{Reuse})_{i,t} &= \beta_0 + \beta_1 Purchase_{i,t} + \gamma' \text{Controls}_{i,t} \\ &\quad \alpha_i + \alpha_{m,t} + \varepsilon_{i,t}, \end{aligned} \tag{3}$$

where $\Delta \log(\text{Reuse})_{i,t}$ is the change in the (logarithmic) amount of reused collateral of bond i over month t. 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.

In addition, we control for various factors that capture changes in the supply and demand of specific collateral. A bond's supply to the repo market increases if that particular bond reopened for auction, thus raising its total amount outstanding. 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

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

[6]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.

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. Bond fixed effects α_i capture any security-specific variation. Following Arrata et al. (2020), we also include maturity bucket×time fixed effects $\alpha_{m,t}$ to account for effects related to the issuer (e.g. rating changes), the yield curve (e.g. haircuts) and market-wide variation. In particular, time fixed effects absorb policy changes such as the introduction and calibration of Eurosystem securities lending facilities. 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 level.

Specification (1) in Table 2 shows the results from this baseline panel regression. The coefficient for *Purchases* is positive and statistically significant at the 5% level. Hence, banks respond to collateral scarcity by increasing the rate at which they reuse available collateral. The coefficient estimate shows that a one percentage point purchase of the Eurosystem as a share of the total outstanding of a bond increases the amount of collateral reused by 0.13%.

Banks may adjust their collateral reuse through different channels. On the one hand, they can increase the rate at which they reuse received collateral. We refer to this as the intensive margin of collateral reuse. On the other hand, dealers can seek to borrow more collateral from other market participants in order to reuse it in further transactions, see Equation 2. We refer to this second channel as the extensive margin of collateral reuse. To study the effect of scarcity on the intensive and extensive margins of collateral reuse, we repeat the above regression for Δ*Reuse rate* and $\Delta \log($*Incoming collateral*$)$ as dependent variables.

Columns (2) and (3) of Table 2 report the results of these regressions. At the intensive margin, the rate at which collateral is reused increases by 1.63 percentage points for a purchase of 1% of the amount outstanding, an effect which is highly statistically significant. At the extensive margin, the volume of incoming collateral increases by 0.10% for the same purchase, and this effect is significant at the 10% level. Hence, banks actively adjust to collateral scarcity along both margins. On the one hand, they reuse existing collateral more efficiently. On the other hand, they also increase their borrowing of a specific piece of collateral when the bond becomes more scarce.

To document that asset scarcity affects reuse in a given bond also at the level of individual dealers, Columns (4) to (6) in Table 2 repeat the same analysis also at the dealer-bond level. The coefficient estimate for the amount reused in Column (4) is even higher than at the bond level analysis at 0.22, and equally significant at the 5% level. This confirms that banks' reuse of specific collateral rises significantly when central bank purchases increase scarcity. The coefficient estimates for Δ*Reuse rate* and $\Delta \log($*Incoming collateral*$)$ as dependent variables in Columns (5) and (6) are of a similar magnitude as in the bond-level regressions. Overall, these results confirm that scarcity induced by Eurosystem asset purchases lead banks to increase their reuse of collateral at both the intensive and extensive margin.

4.2 Extensions

In this section we discuss several extensions of the previous analysis, which we describe in more detail in the Appendix.

First, we expand our universe of bonds to euro area sovereign bonds that are widely held by German banks. In Appendix A, we present aggregate statistics on collateral reuse for the expanded sample and re-estimate the impact of scarcity on reuse. The estimated coefficients align with those for the baseline German sample of bonds and are even more precisely estimated. The most notable difference is that in the extended euro area sample the reuse rate is somewhat less sensitive to scarcity induced by asset purchases. Based on the trading activity of the largest 53 Eurozone banks, Inhoffen and van Lelyveld (2023) report similar results for euro area bonds.

The granularity of our data allows us to study whether the sensitivity of reuse to scarcity depends on the type of collateral. In Appendix C we conduct two analyses to shed light on this question. First, we assess whether on-the-run bonds are more sensitive to asset purchases than off-the-run bonds. Our results provide some evidence that this is the case for European sovereign bonds. Second, we distinguish between collateral with different remaining time to maturity. Specifically, we repeat the sensitivity analysis of the reuse rate for subsets of shorter-dated collateral (bonds with a remaining maturity between 1 and 5 years, medium-dated collateral (remaining maturity between 5 and 10 years) and longer-dated collateral (remaining maturity between 10 and 30 years). For both German and European collateral we observe a decreasing "term-structure" of sensitivities to asset purchases across these maturity bands: the reuse of collateral with shorter and intermediate remaining time to maturity is more sensitive to asset purchases compared to longer-term collateral.

Finally, in Appendix D we provide a back-of-the-envelope calculation to put the estimated increase of collateral reuse in response to asset purchases into perspective. Specifically, we ask the following question: Given a reduction in the supply of collateral, how much additional collateral do banks need to provide through collateral reuse in order to maintain a constant amount of collateral in the market? We find that our estimated coefficients are considerably higher than what results from our calculation above. This apparent overcompensation is likely due to central banks purchasing disproportionately from holders that would otherwise supply these assets as collateral. Consistent with this interpretation, Koijen, Koulischer, Nguyen and Yogo (2021) find that euro area banks were an important net seller of euro area government bonds to the Eurosystem in the PSPP, second only to foreign investors.

5 Collateral reuse and repo market specialness

In Duffie (1996), specialness as a measure of safe asset scarcity depends on the demand for and supply of the specific collateral, but is also a function of the transaction costs faced by investors owning the collateral. In the previous section, we have shown that banks respond to safe asset scarcity induced by central bank asset purchases by adjusting their reuse activity. Hence, they effectively increase the supply of specific collateral in the repo market. However, there is a binding constraint as dealers cannot post more collateral than they receive from other market participants or own outright. As a result, a bond's scarcity in the repo market may depend on its prevailing level of reuse. In this section, we therefore explore how the specialness of specific collateral depends on banks' reuse activity.

In Duffie (1996) and subsequent work, specialness spreads are commonly computed by subtracting from a bond's specific collateral rate the 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 follow their approach and use the specific collateral rate itself instead of the specialness spread to measure bond scarcity premia. Any changes in the general collateral rate will be absorbed by the time fixed effects included in our regressions.

To evaluate the effect of collateral reuse on scarcity premia, we 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:[7]

$$\begin{aligned}\Delta repo\ rate_{i,t} &= \beta_0 + \beta_1 Purchase_{i,t} + \beta_2 Reuse_{i,t-1} + \beta_3 Purchase_{i,t} \times Reuse_{i,t-1} \\ &\quad + \gamma' Controls_{i,t} + \alpha_i + \alpha_{m,t} + \varepsilon_{i,t} \end{aligned} \tag{4}$$

[7] 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 prevailing level of reuse. As a result, repo rates should be 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 again consider the effects of reuse at the extensive and the intensive margin, captured by the overall amount of collateral reused and the reuse rate. Since overall reuse is trending upward in our sample period, we render it stationary by dividing it by outright ownership and taking the logarithm, i.e. log(*Reuse/Outright ownership*). For comparability, both measures of reuse 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 3 presents the estimation results. In Column (1) we estimate the baseline regression without the interaction term. Consistent 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. This is similar in magnitude to Arrata et al. (2020), who report a reduction of 0.78 basis points with regard to a one percent PSPP purchase using daily data for a broader cross-section of euro area sovereign bonds.

In Columns (2) and (3) we include the two measures of reuse as well as the interaction term with PSPP purchases. The coefficients on lagged log(*Reuse/Outright ownership*) and the lagged log(*Reuse Rate*) are both positive and highly statistically significant. Hence, bonds that are reused more strongly are associated with higher repo rates and are thus less special. Crucially, for both measures of reuse the interaction term is significant, both statistically and economically. 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 an additional reduction in the repo rate by 0.67 basis points for each percent of amount outstanding purchased. Hence, when the prevailing amount or rate of reuse of a bond is high, the scarcity induced by central bank asset purchases increases the bond's specialness.

Table IA.7 in the Internet Appendix repeats this analysis for a larger set of euro area bonds for which the banks of our sample are comparably active, yielding very similar results. Hence, our finding that reuse affects the degree to which asset purchases increase specialness is not specific to German Bunds.

How persistent are the effects of central bank purchases on the specialness of specific collateral? And does the prevailing degree of reuse affect the persistence? While we only observe reuse at the quarterly frequency, we can study the dynamic effects of asset purchases on specialness premia at the daily frequency. To this effect, we estimate panel local projections in the spirit of Jorda (2005). Specifically, for each horizon h, we run the following regression

$$\Delta \mathit{repo\ rate}_{i,t+h} = \beta_{0,h} + \beta_{1,h} \mathit{Purchase}_{i,t} + \beta_2' \mathit{Controls} + \alpha_i + \alpha_t + \varepsilon_{i,t+h} \tag{5}$$

and collect the coefficients $\beta_{1,h}$. These measure the dynamic effects of an asset purchase of 1% of the amount outstanding on the specialness premium h days out. Controls in the regression include the log of amount outstanding, a dummy indicating on-the-run status, a dummy indicating cheapest-to-deliver status and α_i and α_t indicate bond and time fixed effects, respectively.

To assess the impact of collateral reuse on the transmission of asset purchases to scarcity premia, we perform a split-sample analysis. Specifically, we run the above regression separately for bonds for which the reuse rate is below or above the 25th percentile, which corresponds to a reuse of 63%. The results are provided in the top panel of Figure 2. They show that central bank asset purchases have fairly persistent effects on repo rates, and that these effects are stronger and last longer for bonds which feature a higher reuse activity. Specifically, the repo rate drops by about 10 basis points for Bunds that trade on special in the first few days after the purchase, and the repo rate remains compressed at that lower level for at least a month. The dynamic impact of purchases is less strong and less persistent for Bund securities that are not on special.

The bottom panel of Figure 2 plots the difference in coefficients $\beta_{1,h}$ across the two groups of bonds for each horizon h along with the 90% confidence interval. While there is little difference in the effect of purchases on specialness premia in the first few days, the wedge widens substantially over time and is statistically significantly different from zero after 20 trading days. Hence, asset purchases increase specialness premia more strongly and substantially more persistently for bonds which feature a high prevailing degree of reuse activity.

Overall, the results in this section highlight the importance of collateral reuse in compensating asset scarcity. Repo rates respond more strongly and persistently to scarcity induced by asset purchases for bonds where reuse activity is already high.

6 Collateral reuse and market functioning

In the previous section, we have shown that banks can dampen scarcity effects by reusing available collateral more efficiently. However, specialness premia are more pronounced and increase more persistently in response to central bank purchases for securities for which reuse activity is already high.

In addition to this asymmetry, the reuse of collateral may also increase the interconnectedness among market participants and thereby propagate or even amplify shocks (Brumm et al., 2023). As a result, market functioning may be impaired. In this section we analyze the degree to which an increased reuse activity affects the functioning of the repo market. We first study the link between reuse rates and delivery failures and volatility in the repo market. We then quantify the impact of reuse on the effect of asset purchases on mispricing in the secondary bond market.

6.1 Collateral Reuse and Repo Market Functioning

The repo market is an essential building block of the financial system, enabling participants to meet short-term funding needs and obtaining specific securities for other transactions. The smooth functioning of the repo market thus ensures efficient capital flows and supports market stability. In this section, we study the role of collateral reuse in shaping the effects of purchase-induced scarcity on repo market quality.

We measure the effective functioning of the repo market using two proxies: fails to deliver and repo rate volatility. Fails to deliver indicate instances where a party does not fulfill its obligation to deliver the agreed-upon security in a repo transaction, reflecting potential counterparty risk and operational inefficiencies. Monitoring fails is essential for gauging repo market conditions and the reliability of counterparties. On the other hand, repo rate volatility, or fluctuations in the interest rates in the repo market, provides insights into the overall liquidity and stability of the financial system. Sudden spikes or fluctuations in repo rates can signal stress in the market, impact borrowing costs and affect broader financial conditions.

We obtain security-level information on failures to deliver for Bund securities from LCH Limited, which is the clearinghouse for various European repo trading platforms, including Euro-MTS, MTS-France, MTS Italy, MTS Associated Markets, CME (BrokerTec), TP Repo (TP ICAP) and Tradeweb. We aggregate the daily fails data to the monthly frequency at which we observe reuse. Volatility in the repo market is measured as the monthly realized volatility of daily special repo rates from BrokerTec.

Figure 3 provides binned scatter plots of bonds' failures to deliver (top panel) and repo-market volatility (bottom panel) against their lagged reuse rate. We measure repo rate volatility as the logarithm of the standard deviation of daily repo rates over the course of a month. We differentiate between bonds that are not on special (specialness spread below 5 bps) and bonds that are on special (specialness spread greater or equal to 5 bps). We group variables into equal-sized bins along the x-axis.

The upper chart shows that securities which are on special experience higher fails rates. More importantly, however, repo fails are strongly positively associated with the lagged reuse rate of a bond for both, special and non-special, securities. For bonds that trade on special, this relationship is strongly non-linear. In particular, those with elevated reuse rates experience considerably higher delivery failures in the following month.

The bottom panel of Figure 3 shows a similar pattern in the relation between repo rate volatility and lagged collateral reuse. Securities that trade on special feature substantially more volatile repo rates. While the repo rate volatility increases in the previous month's reuse rate, the relationship is again visibly convex for special bonds. While reuse rates below 60% do not seem to be associated with increased subsequent volatility, the slope is strongly positive for reuse rates above that level. Combined, these charts thus provide initial evidence that excessive reuse of collateral may be associated with impaired repo market functioning reflected by the occurrence of delivery failures and heightened rate volatility.

Of course, other factors related to the supply and demand of collateral may affect both their reuse and delivery fails and repo rate volatility. We account for such potential confounding factors in regressions of both indicators of repo market functioning on lagged collateral reuse. Specifically, we control for the lagged dependent variable and a comprehensive set of security-specific controls as well as time fixed effects. The regression thus explores the cross-sectional relation between collateral reuse and delivery fails in the next month. For repo market volatility we proceed likewise, using the logarithm of repo rate volatility as dependent variable.

Panel A of Table 4 reports the results for the fails rate. The first column shows that there is a positive relation between collateral reuse and fails in the next month. A one standard deviation higher reuse rate (23 percentage points) raises the fails rate by $3.25 \times 23 \approx 75$ basis points. In Column (2), we add a dummy for bonds that trade on special, which we define as securities with a specialness spread above 5 basis points. While the coefficient indicates that special bonds on average experience a 50 basis points higher fails rate in the next month, controlling for the lagged reuse rate the coefficient is not statistically significant. In the third column, we add an interaction term of the lagged reuse rate and the specialness dummy. This interaction term is highly statistically significant while the coefficient for reuse itself becomes insignificant. This implies that reuse is only associated with a higher fails rate when the bond is special and difficult to borrow in the market for collateral.

As seen in Figure 3, fails rates are visibly higher for bonds with reuse rates above 60%, which roughly corresponds to the 25th percentile in our sample. In Column (4), we thus perform a simple piecewise linear regression for lagged reuse rates below and above this cutoff. While the coefficent for the former is slightly negative and not significantly different from zero, the coefficient for reuse rates above the 25th percentile is economically sizable and highly significant. In line with the calculations above, for securities with reuse rates above 60% a one standard deviation increase in the reuse rate (23 percentage points) is associated with a $6.6 \times 23 \approx 150$ basis points higher fails rate. Importantly, this result continues to hold when adding a dummy for bonds that trade on special in Column (5). In the last column of the table, we again differentiate between bonds that trade on special and those that don't by adding interaction terms in the split-sample analysis. The coefficients show that particularly securities with high reuse rates that are on special feature elevated fails rates in the coming month. For securities with reuse rates above 60% that are also on special, a one standard deviation higher reuse rate increases the fails rate by more than two percentage points. This is sizable given the average fails rate in our sample of 2.8 percent.

Panel B of Table 4 repeats the previous analysis for the monthly repo rate volatility as dependent variable. Consistent with our findings from Figure 3, there is a positive, convex relationship between collateral reuse and repo market volatility in the next month. The results can be summarized as follows. Bonds with high reuse rates feature more volatile repo rates in the coming month. This is true also for securities that trade on special. But it is particularly bonds that are special *and* at the same time feature a high prior reuse rate which experience a higher subsequent repo rate volatility. As the split-analysis shows, this effect is exclusively driven by securities with a reuse rate above 60%.

In sum, these results show that while banks' reuse of safe asset collateral mitigates scarcity effects induced by central bank asset purchases, a high level of reuse is associated with more delivery failures and higher 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 in the repo market.

6.2 Collateral Reuse and Mispricing in the Cash Bond Market

A previous literature has established a close connection between specialness in the repo market and pricing conditions in secondary government bond markets ((Duffie, 1996), (Jordan and Jordan, 1997)). Moreover, it has been shown that purchase-induced bond scarcity can result in mispricing in the secondary market for government bonds (D'Amico et al., 2018). In light of these results, this section investigates the role of collateral reuse for the link between repo market specialness and pricing in the cash market.

To measure the degree of mispricing, we follow (Hu, Pan and Wang, 2013). Specifically, we calculate the yield fitting error for a given security as the difference between the par yield and the yield implied by the curve fitting algorithm popularized by Nelson and Siegel (1987) and later extended by Svensson (1994). Denoting this yield fitting error difference $\Delta Y_{i,t}$, we run the following regression:

$$\begin{aligned}\Delta Y_{i,t} &= \beta_0 + \beta_1 \Delta Specialness_{i,t} + \beta_2 PSPP_{i,t} + \\ &\quad \beta_3 \Delta Specialness_{i,t} \times PSPP_{i,t} + \\ &\quad + \gamma' Controls_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t}. \end{aligned} \tag{6}$$

Table 5 summarizes the results. The first column only uses the daily change in the specialness spread as explanatory variable. The statistically significant coefficient shows that a one standard deviation increase in the specialness spread lowers the yield in the secondary market by 9 basis points compared to the Nelson-Siegel-Svensson curve. Hence, in line with the findings by Jordan and Jordan (1997) for U.S. Treasuries, German Bunds which are more special in the repo market also are more expensive in the secondary market. The second column adds the PSPP purchase relative to the total amount outstanding and an interaction term with specialness as explanatory variables. The coefficients on both terms are significantly negative, indicating that central bank purchases further compress the secondary market yield of government bonds beyond the effect of specialness. The negative coefficient on the interaction term shows that a one percent higher purchased amount lowers the yield by an additional 18 basis points for the same degree of specialness. This finding is in line with D'Amico et al. (2018) who use a purchase dummy to document that on days of Federal Reserve asset purchases, Treasury yields in the secondary market are significantly lower than on other days.

The last two columns repeat the same regression for different sample splits that allow us to study the role of collateral reuse for the link between repo market specialness and secondary market pricing. Column (3) shows the results for securities with low reuse rates in the prior month. While specialness has a larger impact on the yield fitting error in this subsample, there is no additional impact from Eurosystem purchases. This shows that when reuse is low, banks can compensate the scarcity induced by asset purchases and cushion the spillover to the cash bond market. The results are very different for the sample of securities with high reuse rates in the previous month. Here, the direct impact of specialness on yield fitting errors is negligible. That said, purchases significantly amplify the effect of specialness on secondary market yields. This finding is intuitive based on our previous results: when reuse is already high, banks cannot increase their reuse in response to central bank purchases sufficiently to mitigate their effects on pricing conditions in the secondary market.

In sum, the findings in this section highlight that banks' collateral reuse in response to purchase-induced scarcity involves a clear trade-off. When reuse is low, banks can easily adjust it and, as a result, mitigate the effects of central bank purchases on market functioning. When reuse is already high, however, the impact of asset purchases on market functioning gets amplified.

7 Conclusion

In this paper we document that 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 higher rates of delivery failures and increased volatility in the repo market.

Our results suggest that theories of repo market specialness should account for collateral reuse. While existing models such as Duffie (1996) relate specialness to supply frictions, there is no explicit role for reuse to affect the degree of these frictions. Specifically, our findings highlight that the supply of specific collateral is endogenous as dealers adjust their reuse to changing market conditions. However, they are constrained in doing so as they cannot post more collateral than they own outright or receive from other market participants. This constraint, in turn, depends on the prevailing level of reuse and may thus be occasionally binding. Hence, the effects of exogenous changes to the supply of safe assets are potentially time-varying and nonlinear.

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. High reuse rates, in turn, are associated with lower repo market quality. 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 ultimately result in an amplification of shocks.

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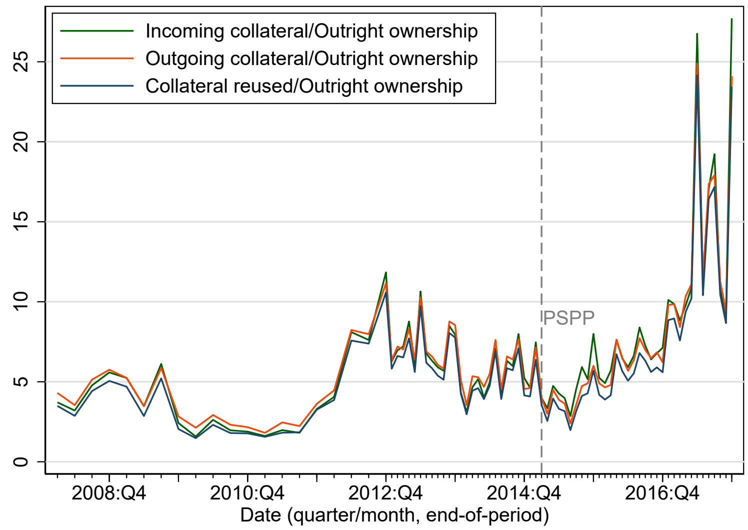
(a) Collateral over Outright Ownership



(b) Reuse Rate

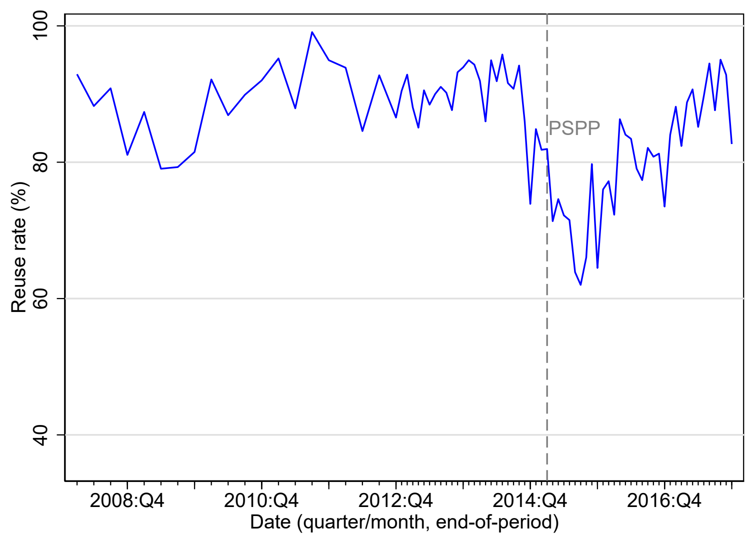
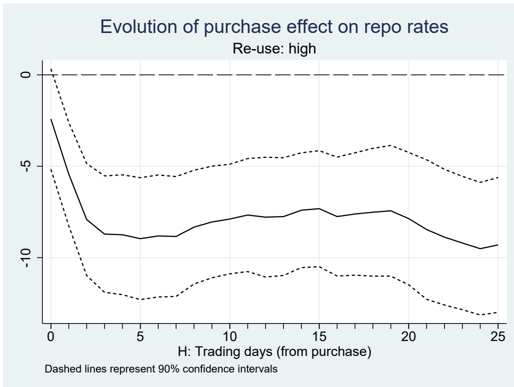


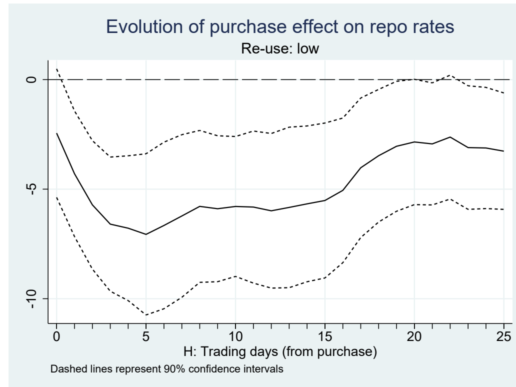
Figure 1: Collateral reuse over time

This figure shows the development of aggregate collateral reuse for German sovereign bonds with remaining maturity between 1 and 30 years. The upper panel plots the multiplier obtained by dividing the amount of incoming, outgoing, and reused collateral in German sovereign bonds by the amount of bonds owned outright. The lower panel 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.

(a) Reuse high



(b) Reuse low



(c) Difference: low - high reuse

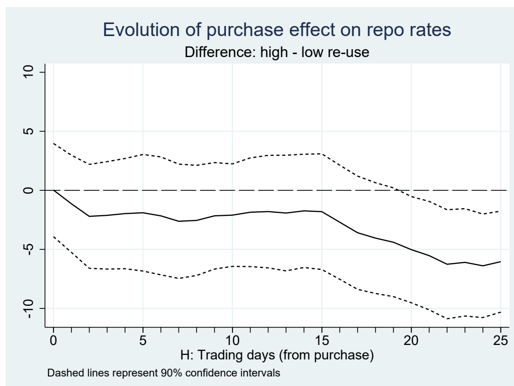
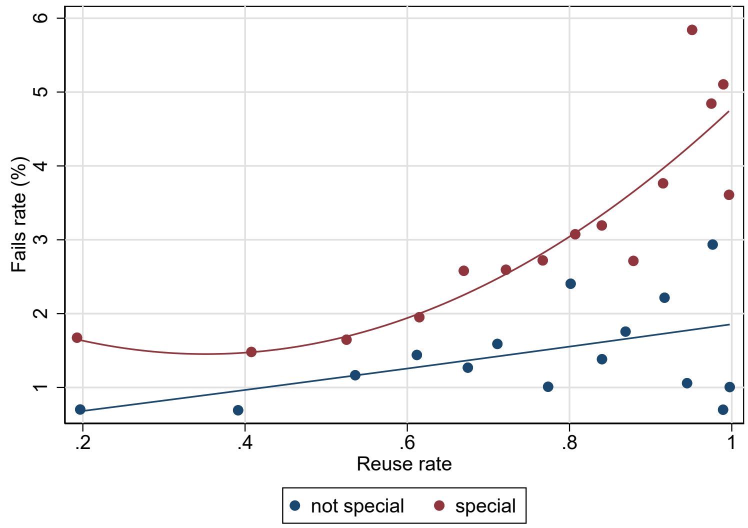


Figure 2: The dynamic effect of asset purchase on repo rates

The figure shows the dynamic effects of asset purchases on repo rates at the daily frequency. We estimate panel local projections in the spirit of Jorda (2005) using a dummy interactions, indicating bonds with a high and low reuse rate (the cutoff is the 25th percentile). Controls in the regression include log of amount outstanding, a dummy indicating on-the-run status, a dummy denoting cheapest-to-deliver status as well as time and bond fixed effects. Figure (a) and (b) show the the dynamic effects of an asset purchase of 1% of the amount outstanding on repo rates up to 25 days. Figure (c) reports the difference between bonds with a high and low reuse rate. The sample consists of the daily panel of German sovereign bonds with remaining maturity between 1 and 30 years. The sample period is March 2015 - December 2017.

(a) Delivery Failures



(b) Repo Rate Volatility

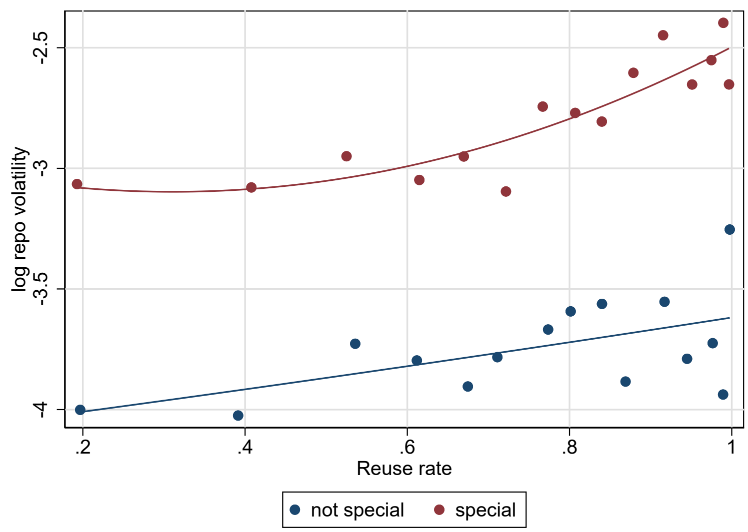


Figure 3: Collateral Reuse and Repo Market Quality

This figure depicts the relationship between reuse rates and measures of repo market quality. The top panel shows the link between reuse rates and the average rate of delivery failures in the next month. The bottom panel provides the relation between reuse rates and repo rate volatility (measured as the logarithm of the standard deviation of repo rates for each month), also in the next month. We differentiate between bonds that are not on special (specialness spread below 5 bps) and bonds that are on special (specialness spread greater or equal to 5 bps). We group variables into equal-sized bins along the x-axis. 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

This table provides summary statistics of the main variables used in regressions throughout the paper. The sample period is March 2015 - December 2017 at the monthly frequency. Panel A describes the bond-level and Panel B the dealer-bond-level data consisting of German sovereign bonds with a remaining maturity between 1 and 30 years. The variables describe monthly changes in the logarithmic amount of collateral reused (Δlog Reuse$_t$), monthly changes in the reuse rate (ΔReuse Rate$_t$), monthly changes in the logarithmic amount of incoming collateral ($\Delta\log$(Incoming collateral)$_t$), monthly changes in the repo rate (ΔRepo Rate$_t$), monthly average rate of delivery failures (Avg. Fails Rate$_t$), and repo rate volatility, measured as the logarithm of the standard deviation of daily repo rates for each month (log(Repo Rate Volatility)$_t$).

Variable	Mean	Std. dev.	Percentiles 25th	50th	75th	N
Panel A: bond-time panel						
$\Delta\log(\text{Reuse})_t$	0.05	1.05	-0.28	0.02	0.35	1,694
ΔReuse Rate$_t$	0.22	22.17	-9.65	-0.09	11.35	1,694
$\Delta\log(\text{Incoming})_t$	0.05	0.91	-0.19	0.00	0.23	1,694
ΔRepo Rate$_t$	-2.07	29.20	-6.98	-1.47	3.22	1,681
Avg. Fails Rate$_t$ (%)	2.83	4.70	0.13	1.08	3.34	1,714
log(Repo Rate Volatility)$_t$	-2.99	1.16	-3.81	-3.18	-2.43	1,714
Panel B: dealer-bond-time panel						
$\Delta\log(\text{Reuse})_t$	0.07	8.24	-0.35	0.00	0.39	10,229
ΔReuse Rate$_t$	0.34	46.59	-3.90	0.00	5.29	10,229
$\Delta\log(\text{Incoming})_t$	0.03	6.91	-0.10	0.00	0.09	10,229

Table 2: 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 at the monthly frequency. The dependent variable in specifications (1) and (4) is changes in logarithmic amount of collateral reused (Δlog Reuse$_t$). 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 incoming collateral (Δ log(Incoming)$_t$). We account also for changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status. The sample consists of German sovereign bonds with a remaining maturity between 1 and 30 years. Specifications (1) - (3) are based on a bond-time panel, and specifications (4) - (6) on a dealer-bond-time panel. The regression model is outlined in Equation (3). The sample period is March 2015 - December 2017. t-statistics based on clustered standard errors are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
	bond level			dealer-bond level		
Dependent variable:	Δ log(Reuse)$_t$	ΔReuse Rate$_t$	Δ log(Incoming)$_t$	Δ log(Reuse)$_t$	ΔReuse Rate$_t$	Δ log(Incoming)$_t$
Asset purchases$_t$ (%)	0.13**	1.63***	0.10*	0.22**	1.25**	0.14
	(2.21)	(3.10)	(1.72)	(2.42)	(2.52)	(1.61)
Δ Amount outstanding$_t$	0.01	-0.16	0.02*	0.03*	0.05	0.04***
	(1.12)	(-1.56)	(1.82)	(1.65)	(0.60)	(2.86)
Dummy: On the run$_t$	0.15	7.52*	-0.04	0.45	5.21	-0.07
	(0.55)	(1.77)	(-0.17)	(0.59)	(1.27)	(-0.10)
Dummy: Cheapest-to-deliver$_t$	-0.05	-0.95	-0.02	-0.12	-0.86	-0.07
	(-0.63)	(-0.59)	(-0.28)	(-0.33)	(-0.42)	(-0.22)
Constant	-0.10	-1.29**	-0.08	-0.20*	-1.10	-0.15
	(-1.45)	(-2.39)	(-1.14)	(-1.65)	(-1.59)	(-1.39)
Fixed effects:						
bond	yes	yes	yes			
maturity bucket×time	yes	yes	yes	yes	yes	yes
dealer×time				yes	yes	yes
dealer×bond				yes	yes	yes
R^2	.2445	.2114	.2719	.1681	.1698	.1128
N	1,691	1,691	1,691	10,054	10,054	10,054

Table 3: Collateral reuse and 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 (6). 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)
$\log(\textit{Reuse/Outright ownership})_{i,t-1}$		1.13***	
		(3.37)	
Asset purchases$_t$ (%) $\times \log(\textit{Reuse/Outright ownership})_{i,t-1}$		-0.52**	
		(-2.50)	
Reuse rate$_{t-1}$			1.47***
			(2.73)
Asset purchases$_t$ (%) $\times$ *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 4: Collateral reuse and repo market quality

This table reports the results of a regression of the average rate of delivery failures (Panel A) and log repo rate volatility (Panel B) on determinants of collateral supply and demand. Avg. Fails Rate$_t$ is the percentage share of cleared collateral that failed to deliver in month t. log(Repo Rate Volatility)$_t$ is the logarithm of the standard deviation of repo rates for each month. *Reuse rate* ranges between 0 and 1 in this table, *Dummy: special* is a dummy that equals 1 of a bond has a sprecialness spread greater 5 bps and it is zero otherwise. In columns (4) - (6) we consider a piece-wise-linear specification, where we estimate separate slopes for high and low reuse rates, where the cutoff point the 25th percentile (reuse rate: 0.63). We control for the lagged level of fails/volatility, lagged yield, lagged repo rate, bond age, remaining maturity and amount outstanding and on-the-run and cheapest-to-deliver status. 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.

Panel A: Average Fails Rate

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	Avg. Fails Rate$_t$(%)					
Reuse rate	3.2480***	3.0847***	0.0898			
	(3.8324)	(4.0273)	(0.2002)			
Dummy: special		0.4787	-2.2724***		0.4200	0.4151
		(1.0133)	(-3.3857)		(0.8996)	(0.4340)
Dummy: special × reuse rate			4.2397***			
			(4.4542)			
Reuse rate low (< P25)				-0.4637	-0.5765	1.0051
				(-0.4954)	(-0.6082)	(1.2405)
Reuse rate high (≥ P25)				6.6337***	6.4628***	-1.3641
				(4.4467)	(4.6624)	(-1.0137)
Dummy: special × reuse rate low (< P25)						-1.6960
						(-1.0106)
Dummy: special × Reuse rate high (≥ P25)						9.2099***
						(4.6854)
Controls	yes	yes	yes	yes	yes	yes
Time fixed effects	yes	yes	yes	yes	yes	yes
R^2	.1835	.1841	.1906	.1916	.192	.1985
N	1,639	1,639	1,639	1,639	1,639	1,639

Panel B: Repo Rate Volatility

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:			log(Repo Rate Volatility)$_t$			
Reuse rate	0.5555***	0.3784***	0.1171			
	(5.6929)	(4.9120)	(1.3485)			
Dummy: special		0.5197***	0.2796***		0.5123***	0.5265***
		(7.4855)	(2.9743)		(7.5189)	(5.2168)
Dummy: special × reuse rate			0.3699***			
			(2.9056)			
Reuse rate low ($<$ P25)				0.0590	-0.0785	0.0497
				(0.6204)	(-0.8295)	(0.4802)
Reuse rate high ($\geq$ P25)				1.0084***	0.7999***	0.2377
				(6.1909)	(5.7829)	(0.8621)
Dummy: special × reuse rate low ($<$ P25)						-0.1489
						(-0.8947)
Dummy: special × Reuse rate high ($\geq$ P25)						0.6638**
						(2.1280)
Controls	yes	yes	yes	yes	yes	yes
Time fixed effects	yes	yes	yes	yes	yes	yes
R^2	.8268	.8389	.8397	.8292	.8409	.8415
N	1,639	1,639	1,639	1,639	1,639	1,639

Table 5: Collateral reuse and mispricing in the secondary bond market

This table reports the results of regression of yield fitting errors on repo market specialness and Eurosystem asset purchases. Bond controls include the log of amount outstanding, time to maturity squared, and dummy variables for cheapest-to-deliver and on-the-run status. 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 at daily frequency. t-statistics based on standard errors clustered at the bond and day level are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)
Dependent variable:	Δ Yield Fitting Error$_t$(%)			
			Reuse low	Reuse high
ΔSpecialness	-0.09***	-0.08***	-0.23***	-0.03
	(-3.32)	(-2.88)	(-3.00)	(-0.92)
PSPP		-0.10***	-0.09**	-0.10**
		(-2.90)	(-2.03)	(-2.56)
Δ Specialness $\times$ PSPP		-0.18*	-0.09	-0.24*
		(-1.70)	(-1.03)	(-1.75)
Bond-level controls	yes	yes	yes	yes
Fixed effects:				
time	yes	yes	yes	yes
bond	yes	yes	yes	yes
R^2	.1724	.1728	.1998	.1944
N	37,600	37,600	17,490	20,109

Internet Appendix accompanying "Safe asset scarcity, collateral reuse, and market functioning"

A Extended Sample of Euro Area Collateral

In this Appendix we expand our sample from German sovereign bonds to a wider universe of euro area sovereign debt. We consider 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.[8] We apply the same filters as described in Section 3 to our data before calculating our reuse measures. That is, we first employ a plausibility check to our data ensuring that outgoing collateral does not exceed the sum of amount owned outright and incoming collateral. Second, we restrict the sample to bonds that are actively used by German dealers as collateral.

Figure IA.1 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 IA.2 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. Dutch, Austrian and Belgian 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.

Table IA.1 shows the results from repeating our main analysis in Table 2 on this wider sample of euro area sovereign bonds. As for the German sample of bonds, we find that increases in collateral scarcity due to central bank asset purchases imply an increase in

[8] 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.

collateral reuse. This effect is even more statistically significant than for the our sample of German collateral. At the same time, estimation coefficients on asset purchases are a bit lower, i.e. reuse in German sovereign bonds is somewhat more sensitive to scarcity induced by asset purchases than other euro area sovereign bonds. We also observe that increases in the amount outstanding of a bond lead to increases in the amount of incoming collateral as well as to decreases in the reuse rate.

B Alternative measures of reuse

As an alternative to the proportional measure of reuse that we employ in our baseline analysis, one can define an upper bound to the amount of collateral reused as follows (FSB, 2016):

$$\textit{Collateral reused}_{ij}^{upper} = \min(\textit{Incoming collateral}_{ij}, \textit{Outgoing collateral}_{ij}). \tag{7}$$

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

Alternatively, a lower bound to the amount of collateral reused is given by:

$$\textit{Collateral reused}_{ij}^{lower} = \max((\textit{Outgoing collateral}_{ij} - \textit{Own assets}_{ij}), 0). \tag{8}$$

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), (7) and (8) 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.

Table IA.2 provides summary statistics of the three reuse measures. All measures show a similar distribution and a very high correlation between each other. The reuse rate obtained via the proportional approach has a 0.98 correlation with both the reuse rate based on the upper and lower measure. Also the reuse rates based on the upper and lower measure have a correlation of 0.93 between themselves. As a further robustness check we repeat our main analyses from Table 2 using the upper/lower bound approach. The estimation results in Table IA.3 are very similar for all three measures and confirm that our findings do not depend on the assumption of proportional reuse of incoming collateral.

C Sensitivity to Collateral Type

The granularity of our data allows us to study whether the sensitivities to asset purchases further depend on the type of collateral. We conduct two such analyses, which extend on the regressions in Table 2.

First, in Table IA.4 we consider the (additional) sensitivity of on-the-run bonds by including an interaction term of asset purchases with the on-the-run dummy. The estimation coefficient for this interaction term is only significant at the 10% level in Specification (4) where we regress the amount of collateral reused for the extended sample of European bonds. This suggests that European on-the-run bonds are more sensitive to purchases than off-the-run bonds.

Second, we distinguish between collateral with different remaining maturities in Table IA.5. That is we repeat the sensitivity analysis of the reuse rate for subsets of shorter-dated collateral (bonds with a remaining maturity of between 1 and 5 years, medium-dated collateral (remaining maturity between 5 and 10 years) and longer-dated collateral (remaining maturity between 10 and 30 years). For both European and German collateral a "term-structure" of sensitivities to asset purchases across these maturity bands is discernible, with shorter- and medium-dated collateral being more sensitive to asset purchases than longer-dated collateral.

D 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[9]:

$$\begin{aligned} \textit{effective amount} &= \textit{base amount} \times \sum_{n=0}^{\infty} \textit{reuse rate}^n \\ &= \frac{\textit{base amount}}{1 - \textit{reuse rate}} \,. \end{aligned} \tag{9}$$

The intuition behind Equation (9) 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 goes to infinity, it can be approximated as a geometric sum, yielding the second identity of Equation (9), 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 (9) to our data. We assume a reuse rate of 80.7%, which is the median value in the dealer-security panel used for estimating Table 2. Hence, at the given value of reuse rate one unit of a bond supports 5.18 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 (9) implies that for a reduction in the base amount by 1%, the new reuse rate in our example needs to be 80.9%, i.e. an increase by 0.2 percentage points. This is considerably lower than the estimated coefficient in Table 2, Column (1). An asset purchase of 1% of the amount outstanding increases the reuse rate by 1.25 percentage points. This conclusion is robust at different levels of reuse and taking into account haircuts, see Table IA.6 in the Internet

[9]We thank Toomas Laarits for this suggestion.

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 considerably larger. Consistent with this notion, Koijen et al. (2021) 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) to the Eurosystem. 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.[10]

[10]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 (9) at $n = 5$ ($n = 10$), we still obtain a multiplier of 3.70 (4.69) 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.

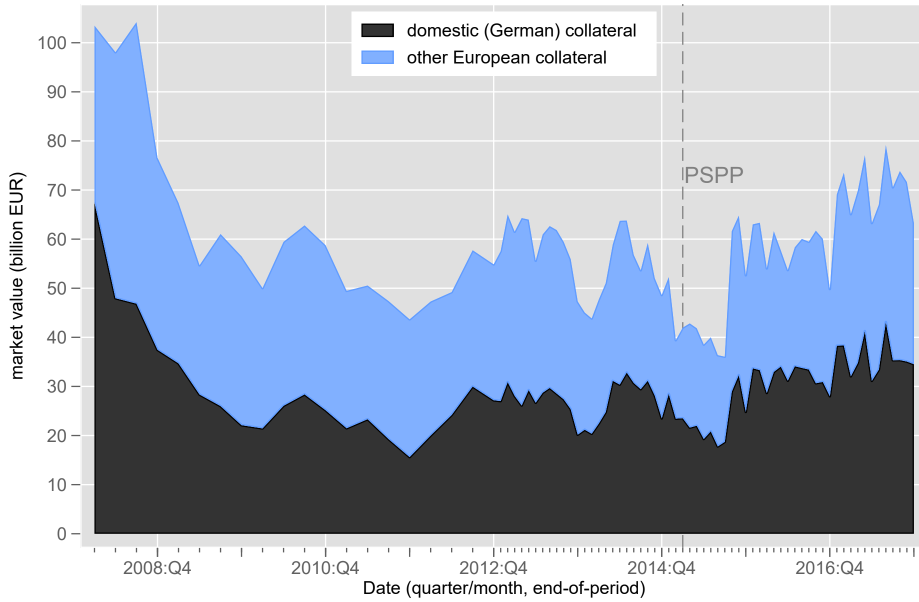


Figure IA.1: Collateral Reused: Domestic vs. foreign
This figure shows the market value of collateral reused for domestic (i.e. German) collateral and collateral by other European countries in our sample. We consider European sovereign bonds with remaining maturity between 1 and 30 years. The sample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

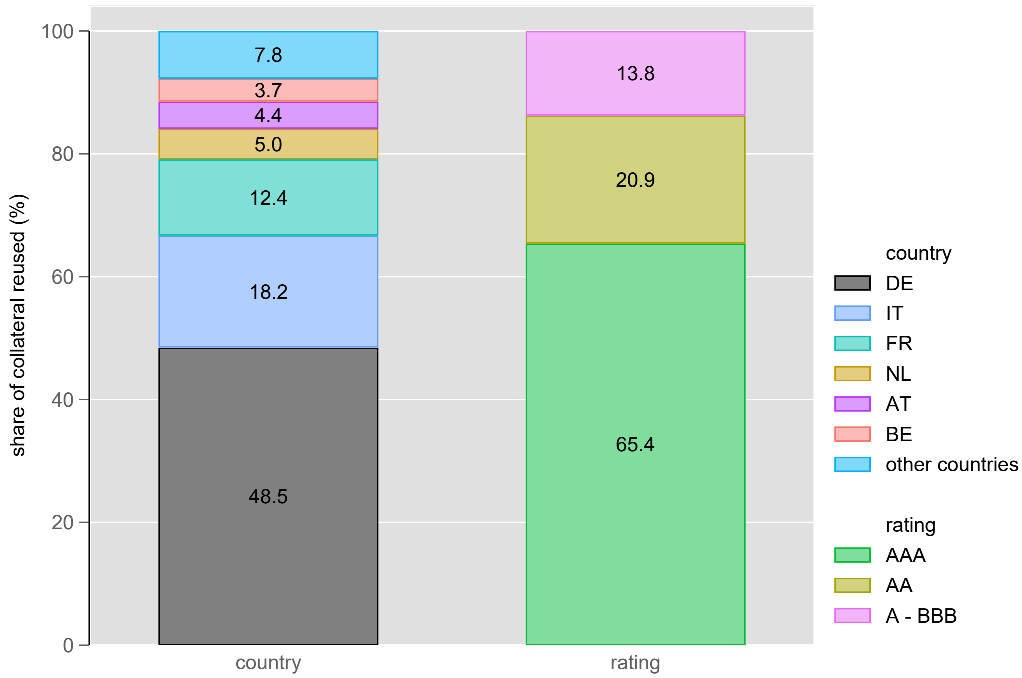


Figure IA.2: Collateral Reused by Issuer Country and Rating
This figure shows the overall share of collateral reused, computed as the time-series average, in our sample, by issuer country (left column) and by issuer rating (right column). The group *other countries* includes Spain, Finland, Greece, Ireland, 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 IA.1:
Asset purchases and collateral reuse: intensive and extensive margin: extended sample of Euro area bonds

The table reports the results of a regression of changes in collateral reuse on asset purchases at monthly frequency. In specifications (1) and (4) the dependent variable is changes in logarithmic amount of collateral reused (Δlog Reuse$_t$), and in specifications (2) and (5) changes in reuse rate (ΔReuse Rate$_t$). The dependent variable in specifications (3) and (6) is changes in the logarithmic amount of incoming collateral (Δ log(Incoming)$_t$). 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 with a remaining maturity between 1 and 30 years. Specifications (1) - (3) are based on a bond-time panel, and specifications (4) - (6) on a dealer-bond-time panel. The regression model is outlined in Equation (3). The sample period is March 2015 - December 2017. t-statistics based on clustered standard errors are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
	bond level			dealer-bond level		
Dependent variable:	Δ log(Reuse)$_t$	ΔReuse Rate$_t$	Δ log(Incoming)$_t$	Δ log(Reuse)$_t$	ΔReuse Rate$_t$	Δ log(Incoming)$_t$
Asset purchases$_t$ (%)	0.17***	0.86**	0.08**	0.15**	0.89***	0.11**
	(2.80)	(2.27)	(2.24)	(2.43)	(2.80)	(1.98)
Δ Amount outstanding$_t$	-0.01	-0.19***	0.02*	0.00	-0.10*	0.02*
	(-0.70)	(-2.98)	(1.91)	(0.04)	(-1.77)	(1.82)
Dummy: On the run$_t$	0.40	6.08***	0.03	0.78**	5.90***	0.64*
	(1.47)	(3.45)	(0.14)	(1.97)	(2.85)	(1.78)
Dummy: Cheapest-to-deliver$_t$	-0.09	0.11	-0.28*	0.07	0.48	0.09
	(-0.54)	(0.07)	(-1.69)	(0.22)	(0.30)	(0.32)
Constant	-0.04	-0.36	-0.04	-0.13*	-0.73**	-0.10*
	(-0.78)	(-1.21)	(-1.38)	(-1.91)	(-2.12)	(-1.75)
Fixed effects:						
bond	yes	yes	yes			
maturity bucket×time	yes	yes	yes	yes	yes	yes
dealer×time				yes	yes	yes
dealer×bond				yes	yes	yes
R^2	.246	.2624	.2689	.1382	.1484	.1073
N	6,646	6,646	6,646	35,026	35,026	35,026

Table IA.2:
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.

			Std.	Percentiles			Correlation		
Row	Variable	Mean	dev.	25th	50th	75th	(1)	(2)	(3)
(1)	$reuse\ rate^{lower}$ (%)	70.4	29.0	59.8	80.0	92.8	1		
(2)	$reuse\ rate^{prop.}$ (%)	72.3	28.2	63.3	81.4	93.3	0.98	1	
(3)	$reuse\ rate^{upper}$ (%)	74.6	28.6	66.1	84.6	94.9	0.93	0.98	1

Table IA.3:
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 2 using the upper- and lower-bound reuse as dependent variable in the regression instead. The dependent variable is changes in logarithmic amount of collateral reused (Δlog(Reuse))$_t$) in specifications (1) - (3), and changes in reuse rate (ΔReuse Rate$_t$) in specifications (4) - (6). In specifications (1) and (4) we emply the lower bound measure for reuse instead, and in specifications (3) and (6) the upper bound measure. Panel A is at the bond level and specifications (2) and (5) are identical to specifications (1) and (2) in Table 2, respectively. Panel B is at the dealer-bond level and specifications (2) and (5) therein are identical to specifications (4) and (5) in Table 2, respectively. 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 clustered standard errors are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Panel A: bond level

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	Δ log(Reuse)$_t$			ΔReuse Rate$_t$		
Reuse computation:	Lower bound	Prop. measure	Upper bound	Lower bound	Prop. measure	Upper bound
Asset purchases$_t$ (%)	0.13**	0.13**	0.13**	1.51***	1.63***	1.73***
	(2.30)	(2.21)	(2.19)	(2.75)	(3.10)	(3.22)
Δ Amount outstanding$_t$	0.01	0.01	0.01	-0.20*	-0.16	-0.12
	(0.80)	(1.12)	(1.17)	(-1.85)	(-1.56)	(-1.22)
Dummy: On the run$_t$	0.29	0.15	0.11	9.99**	7.52*	4.89
	(1.07)	(0.55)	(0.41)	(2.21)	(1.77)	(1.22)
Dummy: Cheapest-to-deliver$_t$	-0.06	-0.05	-0.05	-1.40	-0.95	-0.81
	(-0.72)	(-0.63)	(-0.62)	(-0.83)	(-0.59)	(-0.52)
Constant	-0.10	-0.10	-0.10	-1.16**	-1.29**	-1.37**
	(-1.49)	(-1.45)	(-1.44)	(-2.08)	(-2.39)	(-2.55)
Fixed effects:						
bond	yes	yes	yes	yes	yes	yes
R^2	.2394	.2445	.2428	.2114	.2114	.205
N	1,691	1,691	1,691	1,691	1,691	1,691

Panel B: dealer-bond level

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	$\Delta\log(\text{Reuse})_t$			$\Delta\text{Reuse Rate}_t$		
Reuse computation:	Lower bound	Prop. measure	Upper bound	Lower bound	Prop. measure	Upper bound
Asset purchases$_t$ (%)	0.23**	0.22**	0.22**	1.11**	1.25**	1.32***
	(2.48)	(2.42)	(2.42)	(2.23)	(2.52)	(2.63)
Δ Amount outstanding$_t$	0.02	0.03*	0.03*	0.03	0.05	0.08
	(1.15)	(1.65)	(1.74)	(0.36)	(0.60)	(1.05)
Dummy: On the run$_t$	0.62	0.45	0.40	5.99	5.21	3.52
	(0.74)	(0.59)	(0.52)	(1.41)	(1.27)	(0.88)
Dummy: Cheapest-to-deliver$_t$	-0.06	-0.12	-0.12	-0.78	-0.86	-0.75
	(-0.19)	(-0.33)	(-0.34)	(-0.38)	(-0.42)	(-0.36)
Constant	-0.20	-0.20*	-0.20*	-0.93	-1.10	-1.18*
	(-1.63)	(-1.65)	(-1.65)	(-1.35)	(-1.59)	(-1.68)
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	.1586	.1681	.1678	.1639	.1698	.1717
N	10,054	10,054	10,054	10,054	10,054	10,054

Table IA.4:
Asset purchases and collateral reuse: intensive and extensive margin
Robustness check: Sensitivity of on-the-run bonds.

This table provides an extension to the analysis of Table 2 by estimating the sensitivity of on-the-run bonds to asset purchases. 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 addition to the specification of Table 2 we include an interaction term (Asset purchases$_t$ (%) $\times$ Dummy: On the run$_t$) that captures the additional sensitivity of on-the-run bonds to asset purchases. In specifications (1) and (4) the dependent variable is changes in logarithmic amount of collateral reused (Δlog Reuse$_t$), and in specifications (2) and (5) changes in reuse rate (ΔReuse Rate$_t$). The dependent variable in specifications (3) and (6) is changes in the logarithmic amount of incoming collateral (Δ log(Incoming)$_t$). We account also for changes in the amount outstanding and control for on-the-run and cheapest-to-deliver status. The sample consists of German sovereign bonds in specifications (1) - (3), and of European 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 are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
	German collateral			European collateral		
Dependent variable:	Δ log(Reuse)$_t$	ΔReuse Rate$_t$	Δ log(Incoming)$_t$	Δ log(Reuse)$_t$	ΔReuse Rate$_t$	Δ log(Incoming)$_t$
Asset purchases$_t$ (%)	0.03	1.21**	-0.00	0.09	0.53	0.03
	(1.23)	(2.10)	(-0.07)	(1.64)	(1.31)	(1.25)
Asset purchases$_t$ (%) $\times$ Dummy: On the run$_t$	0.28	1.17	0.28	0.28*	1.08	0.16
	(1.63)	(1.09)	(1.61)	(1.96)	(1.35)	(1.35)
Δ Amount outstanding$_t$	0.01	-0.17	0.01	-0.01	-0.21***	0.01*
	(0.87)	(-1.60)	(1.61)	(-1.03)	(-3.14)	(1.75)
Dummy: On the run$_t$	-0.46	4.96	-0.65	-0.11	4.08*	-0.26
	(-0.82)	(1.04)	(-1.18)	(-0.33)	(1.72)	(-0.93)
Dummy: Cheapest-to-deliver$_t$		-0.01	-0.78	0.02	-0.07	0.21
	(-0.15)	(-0.49)	(0.23)	(-0.39)	(0.13)	(-1.60)
Constant	-0.02	-0.97*	-0.00	0.02	-0.14	-0.01
	(-0.66)	(-1.70)	(-0.00)	(0.44)	(-0.46)	(-0.57)
Fixed effects:						
bond	yes	yes	yes	yes	yes	yes
maturity bucket$\times$country$\times$time	yes	yes	yes	yes	yes	yes
R^2	.2638	.2122	.2979	.2466	.2626	.2695
N	1,691	1,691	1,691	6,646	6,646	6,646

Table IA.5:
Asset purchases and collateral reuse: intensive and extensive margin
Robustness check: Comparison across bond maturities.

This table provides an extension to the analysis of Table 2 by separating shorter- and longer-dated bonds in their sensitivity to asset purchases. 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 Panel A the dependent variable is changes in logarithmic amount of collateral reused (Δlog Reuse$_t$), and in Panel B changes in reuse rate (ΔReuse Rate$_t$). The dependent variable in Panel C is changes in the logarithmic amount of incoming collateral (Δ log(Incoming)$_t$). Specification (1) in each of the three panels repeats specifications (1) - (3) of Table 2, respectively, and is based on all bonds with a remaining maturity between 1 and 30 years. In specifications (2) and (6) the remaining maturity is between 1 and 5 years, while in specifications (3) and (7) it is between 5 and 10 years. The sample in specifications (4) and (8) is for bonds with a remaining maturity of between 10 and 30 years. The sample consists of German sovereign bonds in specifications (1) - (4), and in specifications (5) - (8) of European sovereign bonds as described in Appendix A. 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 are provided in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Panel A: changes in logarithmic amount of collateral reused

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	German collateral				European collateral			
Remaining maturity:		$1-5$ years	$5-10$ years	10+ years		$1-5$ years	$5-10$ years	10+ years
Dependent variable:	Δlog Reuse$_t$							
Asset purchases$_t$ (%)	0.13**	0.23**	0.15**	0.06	0.17***	0.22*	0.10	0.26
	(2.21)	(2.30)	(2.56)	(1.08)	(2.80)	(1.96)	(1.50)	(1.59)
Δ Amount outstanding$_t$	0.01	0.03*	-0.01	0.07	-0.01	0.00	0.00	-0.08**
	(1.12)	(1.81)	(-0.45)	(1.23)	(-0.70)	(0.10)	(0.20)	(-2.02)
Dummy: On the run$_t$	0.15	-0.23	0.51	0.00	0.40	0.07	-0.11	0.15
	(0.55)	(-0.45)	(1.10)	(.)	(1.47)	(0.10)	(-0.28)	(0.47)
Dummy: Cheapest-to-deliver$_t$	-0.05	-0.32*	0.05	-0.07	-0.09	-0.24	-0.39	0.03
	(-0.63)	(-1.72)	(0.53)	(-0.86)	(-0.54)	(-0.65)	(-1.39)	(0.41)
Constant	-0.10	-0.11	-0.17**	-0.04	-0.04	-0.06	0.03	0.03
	(-1.45)	(-1.20)	(-2.67)	(-0.87)	(-0.78)	(-0.99)	(0.45)	(0.23)
Fixed effects:								
bond	yes	yes	yes	yes	yes	yes	yes	yes
maturity bucket×country×time	yes	yes	yes	yes	yes	yes	yes	yes
R^2	.2445	.3226	.1404	.2712	.246	.3007	.1963	.213
N	1,691	791	514	381	6,646	2,807	2,285	1,538

Panel B: changes in reuse rate

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	German collateral				European collateral			
Remaining maturity:		$1-5$ years	$5-10$ years	10+ years		$1-5$ years	$5-10$ years	10+ years
Dependent variable:	ΔReuse Rate$_t$							
Asset purchases$_t$ (%)	1.63***	1.64**	3.54***	0.41	0.86**	1.11*	1.45**	-0.71
	(3.10)	(2.51)	(3.60)	(0.15)	(2.27)	(1.83)	(2.54)	(-0.65)
Δ Amount outstanding$_t$	-0.16	0.01	-0.68**	0.99	-0.19***	-0.07	-0.29***	-0.55**
	(-1.56)	(0.10)	(-2.65)	(0.70)	(-2.98)	(-0.70)	(-3.05)	(-2.45)
Dummy: On the run$_t$	7.52*	2.46	21.34***	0.00	6.08***	4.57	5.59**	0.61
	(1.77)	(0.33)	(2.79)	(.)	(3.45)	(1.28)	(2.02)	(0.24)
Dummy: Cheapest-to-deliver$_t$	-0.95	-4.74	2.62	-1.16	0.11	-1.44	-0.70	-1.66
	(-0.59)	(-1.26)	(1.12)	(-0.40)	(0.07)	(-0.41)	(-0.29)	(-0.65)
Constant	-1.29**	-0.53	-4.17***	-0.43	-0.36	-0.37	-0.72	1.84*
	(-2.39)	(-0.88)	(-3.48)	(-0.17)	(-1.21)	(-1.07)	(-1.27)	(1.78)
Fixed effects:								
bond	yes	yes	yes	yes	yes	yes	yes	yes
maturity bucket×country×time	yes	yes	yes	yes	yes	yes	yes	yes
R^2	.2114	.1888	.2619	.2839	.2624	.2876	.2544	.2532
N	1,691	791	514	381	6,646	2,807	2,285	1,538

Panel C: changes in the logarithmic amount of incoming collateral

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	German collateral				European collateral			
Remaining maturity:		$1-5$ years	$5-10$ years	10+ years		$1-5$ years	$5-10$ years	10+ years
Dependent variable:	Δ log(Incoming)$_t$							
Asset purchases$_t$ (%)	0.10*	0.21**	0.08	0.05	0.08**	0.15**	0.09**	0.05
	(1.72)	(2.07)	(1.58)	(1.10)	(2.24)	(2.17)	(2.09)	(0.50)
Δ Amount outstanding$_t$	0.02*	0.03*	0.01	0.05	0.02*	0.03*	0.01	0.00
	(1.82)	(1.99)	(0.49)	(1.79)	(1.91)	(1.66)	(1.11)	(0.10)
Dummy: On the run$_t$	-0.04	-0.36	0.05	0.00	0.03	-0.31	-0.15	0.09
	(-0.17)	(-0.74)	(0.12)	(.)	(0.14)	(-1.17)	(-0.46)	(0.37)
Dummy: Cheapest-to-deliver$_t$	-0.02	-0.22	-0.01	-0.05	-0.28*	-0.12	-0.62	-0.05
	(-0.28)	(-1.34)	(-0.09)	(-0.64)	(-1.69)	(-0.69)	(-1.65)	(-0.54)
Constant	-0.08	-0.11	-0.09*	-0.04	-0.04	-0.07	-0.05	-0.02
	(-1.14)	(-1.18)	(-1.75)	(-0.85)	(-1.38)	(-1.63)	(-1.03)	(-0.22)
Fixed effects:								
bond	yes	yes	yes	yes	yes	yes	yes	yes
maturity bucket×country×time	yes	yes	yes	yes	yes	yes	yes	yes
R^2	.2719	.3882	.1474	.159	.2689	.3877	.1973	.2624
N	1,691	791	514	381	6,646	2,807	2,285	1,538

Table IA.6:
Adjustment to reuse rates necessary to compensate supply reductions.
This table provides a robustness check to the analysis in Section D using a wide set of potential parameters. Taking into account a haircut HC that is applied each time that collateral is (re-)used, Equation (9)) 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
70.00	0.00	70.30	0.30
80.00	0.00	80.20	0.20
80.70	0.00	80.89	0.19
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
70.00	3.00	70.33	0.33
80.00	3.00	80.23	0.23
80.70	3.00	80.92	0.22
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
70.00	5.00	70.35	0.35
80.00	5.00	80.25	0.25
80.70	5.00	80.95	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.7:
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 3 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 (6). 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$_t$ (%) $\times$ log(*Reuse*/*Outright ownership*)$_{i,t-1}$		-0.61**	
		(-2.31)	
Reuse rate$_{t-1}$			1.23**
			(2.43)
Asset purchases$_t$ (%) $\times$ *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