Regulatory Effects on Short-Term Interest Rates

Angelo Ranaldo
University of St. Gallen

Patrick Schaffner
Bank of England,
University of St. Gallen

Michalis Vasios
Norges Bank Investment Management

November 20, 2019

Abstract

We analyse the effects of EMIR and Basel III regulations on short-term interest rates. EMIR requires central clearing houses (CCP) to continually acquire safe assets, thus expanding the lending supply of repurchase agreements (repo). Basel III, in contrast, disincentivises the borrowing demand by tightening banks' balance sheet constraints. Using unique datasets of repo transactions and CCP activity, we find compelling evidence for both supply and demand channels. The overall effects are decreasing short-term rates and increasing market imbalances in various forms, all of which entail unintended consequences originated from the new regulatory framework.

We are grateful for valuable comments from Jonathan Acosta-Smith, Christoph Aymanns, Alexander Bechtel, Evangelos Benos, Giovanni Calice, Pavel Chichkanov, Sean McGrath, David Murphy, Gerardo Ferrara, Mariam Harfush-Pardo, Pedro Gurrola-Perez, Russell Jackson, Linda Kirschner, Philipp Lentner, Katia Pascarella, Loriana Pelizzon, Dagfinn Rime, Gary Robinson, Pablo Rovira Kaltwasser, Glenn Schepens, Guillaume Vuillemey and participants of the conferences BCBS/CEPR, CARF, Central Bank Workshop on Microstructure of Financial Markets, ECB Money Market, ESSEC-Banque de France, SAFE, SFI research days, and seminars at the Bank of England, Bank of Italy, BI (Oslo), ESCP, LUISS, and the Swiss National Bank. We also acknowledge the support of the Bank of England and of the Swiss Institute of Banking and Finance. The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or Norges Bank Investment Management, and Michalis Vasios has worked on this paper while he was at the Bank of England.

Contents

1 Introduction **1**

2 Regulatory Context **7**
2.1 European Market Infrastructure Regulation 7
2.2 Basel III 11

3 Data **12**
3.1 Repo Interbank Market 13
3.2 CCP Investments 16
3.3 Other Data 17

4 Supply Effects **20**

5 Demand Effects **23**

6 Additional Tests **27**
6.1 Rate Dispersion 28
6.2 Individual Behaviours 32
6.3 Robustness Tests 36

7 Conclusion **39**

References **41**

List of Figures

1 European Repo Rates 45
2 Impact of Repo Trading on the Leverage Ratio 46
3 Balance Sheet Impact around Reporting Days 47

List of Tables

1 Breakdown of the Repo Dataset 48
2 Supply Effect on Repo Rates 49
3 Demand Effects on Repo Rates 50
4 Effects on Repo Rate Dispersion 51
5 Effects on Banks' Individual Behavior 52

1 Introduction

The market for repurchase agreements ("repo") has become the main source of funding liquidity that allows financial market participants to manage their inventory of cash and securities.[1] In addition to dealer and banks, the new regulation governing the well-functioning of the over-the-counter (OTC) derivatives market made central counterparties (CCPs) major participants in the European repo market. In the words of Benoît Cœuré (2019) "*CCPs act as major repo counterparties when reinvesting the large amounts of collateral they collect. Disruptions affecting, or caused by, a CCP can have ripple effects through the euro repo market, which may affect the conduct of monetary policy.*"

In addition to these structural changes, some puzzling patterns emerged in money markets. As illustrated in Figure 1, since 2015 European repo rates dropped below the central bank deposit rate exhibiting wider cross-sectional dispersion and marked declines on reporting days of the Basel III leverage ratio (BIS, 2017). These issues have gained attention from regulators and practitioners raising several compelling questions: How does the new regulatory framework in banking and financial market infrastructures affect the repo market? Has it created unintended consequences by bringing down and spreading out short-term interest rates? And if it does, why?

[Insert Figure 1 here.]

To address these important questions, we analyse unique regulatory data from the investment activity of UK CCPs together with a comprehensive

[1] A repo is a collateralised loan to borrow cash based on a simultaneous sale and forward agreement to repurchase securities at the maturity date. Throughout this paper, we refer to borrowing and lending repo cash.

dataset of European repos. We identify two key regulatory effects, one affecting the repo supply (or reverse repos) and the other affecting the repo demand. On the supply side, the European market infrastructure regulation (EMIR) requires European CCPs to turn their unsecured cash holdings from the collection of margins into highly liquid securities. In practice, CCPs obtain these securities by entering into reverse repos (i.e., they lend cash against collateral). We find that the repo supply enforced by this regulation puts significant downward pressure to short-term interest rates. On the demand side, the Basel III leverage ratio entails that repos expand the balance sheet of financial intermediaries, whereas reverse repos do not. We find that CCPs' downward pressure on short-term rates strengthens during the regulatory reporting dates when the leverage ratio bites banks' repo cash borrowing demand the most. To shed light on the transmission mechanism, we show that those banks borrowing from CCPs offload their liquidity surpluses by lending (borrowing) more (less) in the interbank market.

A better understanding of how new regulations affect short-term interest rates is relevant for regulators who have imposed a number of regulatory constraints on banks with unknown effects and interactions (e.g. Haldane, 2017; Cœuré, 2017). Whilst new prudential policies strengthen financial stability, regulations such as Basel III leverage ratio might have created unintended effects such as disincentivising repo intermediation (Duffie, 2016),[2] inducing collateral scarcity (Cœuré, 2012) and window-dressing at the end of report-

[2]For instance, a repo causes almost no increase in the risk of the dealer's balance sheet but the leverage rule requires significantly more capital creating a "debt overhang" problem in the sense that dealer's creditors benefit from the improved safety of their claims at shareholders' expense (Duffie, 2017).

ing periods (BIS, 2017, pp. 20–28).[3] Furthermore, the Dodd-Frank Act and EMIR implementation in U.S. and Europe, respectively, has made central clearing mandatory for interest rate swaps and credit default swaps (CDS) indices, thus making CCPs large actors in financial markets. Understanding these issues is crucial for phasing-in and redesigning the regulatory framework aiming at reaching the desired level of market efficiency and financial stability (Duffie, 2018). Our study is also relevant to central banks as many monetary policies are implemented through short-term rates.

Our first contribution is to show the causal effect of the new regulation governing clearing infrastructures on the supply side of the repo market. The main function of CCPs is to reduce counterparty risk by collecting initial margin and default fund contributions. As a result, CCPs hold vast amounts of cash. For instance, the total cash held daily by the top 10 European CCPs in 2016 exceeded EUR140 billions.[4] EMIR states that at least 95% of any cash position that remains in a CCP's margin accounts or default fund overnight must be invested into government bonds or reverse repos or deposited with a central bank.[5] This means that clearing houses are required to reinvest cash in a given set of highly safe and liquid assets available on the market on a daily basis. In practice, the CCPs in our sample comply to the EMIR requirement by lending repo cash for high quality collateral in the over-the-counter (OTC)

[3]For example, the BIS (2017, p. 22) writes that "regulation calculated on the basis of the banks' balance sheet size [...] has had a pronounced impact on repo market activity." Further, it observes that differences in the behaviour of banks across jurisdictions with different balance sheet constraints support this hypothesis. In particular, it shows that banks not subject to US or UK leverage ratio regulation decreased their repo trading volumes much less than other banks. The ECB (Grill et al., 2017, p. 161) repeats concerns raised by the industry that "regulatory reforms have significantly reduced the willingness of banks to provide repo services and contributed to volatility and market dislocations around the balance sheet reporting dates."

[4]These estimates are based on the CPMI-IOSCO Public Quantitative Disclosures by European CCPs at the end of the first quarter of 2016.

[5]See Articles 44-45 of EMIR (EC, 2013, p. 63). For further details, see section 2.1.

bilateral segment of the repo market. The investment of European CCPs in the reverse repo market is substantial. For instance, out of the EUR140 billion cash held by the top 10 European CCPs in 2016, about EUR60 billion were invested daily in reverse repos (according to CPMI-IOSCO disclosures). This represents a sizeable amount compared to the total daily borrowed volume of about EUR300 billion in the Euro interbank repo market.

To test the supply hypothesis, we perform a series of panel regressions with fixed-effects for the country of the collateral asset. Daily excess rates, defined as the difference between the interbank repo rate and the central bank deposit rate, are regressed on aggregate CCPs' investment on reverse repos. In addition to be determined by regulation and by the amount of cash accumulated on CCPs' margin accounts, notice that CCPs' reverse repos are conducted in the *OTC segment* while we analyse the impact on *interbank* rates. Thus, CCPs' repo can be seen as an instrumental variable (IV) measuring exogenous supply to the interbank repo market. We control for other potential factors including interbank order flow (i.e., borrower-initiated minus lender-initiated repos) that should determine price formation according to microstructure theories, risk variables accounting for possible margin procyclicality, CCPs' purchases in the cash bond market, which can induce indirect effects on short-term rates such as "specialness," and Quantitative Easing (QE) effects that can create collateral scarcity and excess liquidity. The main finding is that to conform to new regulation, CCPs' repo cash lending exerts a pervasive and systematic downward pressure on short-term rates, thus supporting the supply hypothesis.

Our second contribution is to show how the new regulation on the clearing infrastructure also affects the demand side of repo markets. To do this, we exploit the interaction between EMIR and Basel III regulations. The main idea is to analyse the impact of the exogenous variation of CCPs' cash supply on the downward-sloping demand curve for repos during the Basel III leverage ratio reporting periods. Note that only repo contracts and not reverse repos expand bank's balance sheets.[6] Hence, banks are less inclined to *demand* repos whereas repo supply remains essentially unaffected.[7]

To test the demand effect, we design a difference-in-differences setting in the spirit of Du, Tepper, and Verdelhan (2018). In our setting, repo contracts expiring after (before) the quarter-end represent the "treated group" ("control group") as they are (not) subject to the leverage ratio requirement and thus generate higher capital costs. We then test whether the negative effect of the CCP activity on short-term rates is stronger for repo contracts that expire *after* the quarter-end reporting date. The main finding is that the negative CCP impact on short-term rates increases during quarterly reporting dates, that is, when the Basel III leverage ratio imposes balance sheet constraints on banks demanding repos. This evidence suggests that the joint regulatory effects of EMIR and Basel III further decrease short-term rates, thus supporting the demand hypothesis.

In the remainder of our paper, we delve into the differential effect and the transmission mechanism of regulations. To do this, we analyse which repos and banks are affected the most. First, we carry out panel regression analysis on yield differentials between repos with different collateral. We find that the

[6]The repo cash enters on the asset side and the repo debt on the liability side of the repo borrower's balance sheet while the pledged asset remains on its asset side. Regarding reverse repos, the lent cash leaving the lender's balance sheet equals the claim on the repo counterparty remaining in the balance sheet. Collateral assets are excluded because they are temporary purchases. See section 2.2 for details.

[7]Note that the leverage ratio is an unweighted risk measure, suggesting that it is the balance sheet size rather than the asset quality that matters. Also, the tenors (shorter than the thirty-day LCR cut-off time) and collateral assets (all are Level 1 High Quality Liquid Assets (HQLA)) analysed in this paper are unaffected by other regulations such as the Liquidity Coverage Ratio (LCR) (cf. BIS, 2017, pp.27–28), the Net Stable Funding Ratio (NSFR) and Risk Weighted Assets (RWA).

purchases of collateral assets by CCPs widen yield differentials and that the repo contracts with the lowest rate are (negatively) affected the most. From the perspective of the safe asset literature, this finding suggests that regulation chiefly affects repos bearing largest convenience premia, i.e. offering more safety or liquidity benefits. Second, we perform panel regressions at the bank level. By entering a bilateral repo contract with a CCP, a bank suffers from a cash surplus, a shortage of HQLA assets, and an expansion of the balance sheet. We find that banks who are borrowing counterparties with the CCPs in our sample tend to offset any consequent cash surpluses and asset shortages by lending more and borrow less in the interbank market.

We contribute to at least three strands of the literature: First, to the growing literature on intermediary asset pricing (e.g., He & Krishnamurthy, 2013; Adrian, Etula, & Muir, 2014; He, Kelly, & Manela, 2017). We do so by showing that regulations have created new and important market participants, i.e. clearing houses, that affect how financial intermediaries price and trade short-term rates.[8].

Second, we contribute to the literature on repos, which represent an important category of safe assets (Gorton, 2017).[9] Only few papers analyse the regulatory effects on repo rates.[10] Our study is the first to highlight how the new mandatory framework including EMIR contributes to dragging down repo rates (below central bank deposit rates) and widening their dispersion.

[8]Several recent papers study regulatory effects on market liquidity (e.g., Adrian, Boyarchenko, & Shachar, 2017; Trebbi & Xiao, 2017; Bicu, Chen, & Elliot, 2017) and on risk-taking (e.g., Acosta-Smith, Grill, & Lang, 2018) and arbitrage (Du et al., 2018)

[9]Several recent papers analyse repo markets in the United States (e.g. Copeland, Martin, & Walker, 2014; Gorton & Metrick, 2012; Krishnamurthy, Nagel, & Orlov, 2014) and in Europe (e.g. Mancini, Ranaldo, & Wrampelmeyer, 2016; Boissel, Derrien, Ors, & Thesmar, 2017).

[10]For instance, Munyan (2015) documents calendar effects during reporting periods. Studying GILT repos, Kotidis and van Horen (2018) find that banks with more binding leverage ratio offer their smaller clients lower rates and reduced repo volume.

The regulatory effects uncovered in this paper represent a new explanation for low and dispersed short-term rates that complements narratives on collateral scarcity and Quantitative Easing impacts, as we demonstrate empirically.[11]

Third, we contribute to the nascent literature on central clearing that is mostly devoted to CDS pricing in the post-crisis regulatory regime.[12] The novelty of our study is to show that clearing houses on their own have become important players with "preferred [regulatory] habitats" for safe and liquid assets affecting intermediaries' behaviours.[13]

The remainder of the paper is organized as follows: Section 2 introduces the regulatory reforms. Section 3 presents our datasets. Section 4 and Section 5 analyse the supply and demand hypothesis, respectively. 6 provides additional analyses. Section 7 concludes.

2 Regulatory Context

The effects we analyse are relevant to two pieces of European regulation: the EMIR regulation on market infrastructures and the Basel III leverage ratio. Below we provide an overview of them.

2.1 European Market Infrastructure Regulation

In July 2012 the European Union issued EMIR, which lays down the regulatory framework for over-the-counter (OTC) derivatives, CCPs, and trade

[11] Some recent papers study the effects on unconventional monetary policies on repo markets (e.g., Arrata, Nguyen, Rahmouni-Rousseau, & Vari, in press; Corradin & Maddaloni, in press; Pelizzon, Subrahmanyam, Tomio, & Uno, 2018).

[12] See, for instance, Arora, Gandhi, and Longstaff (2012); Loon and Zhong (2014); Duffie, Scheicher, and Vuillemey (2015); Du, Gadgil, Gordy, and Vega (2016).

[13] The preferred habitat hypothesis developed by Modigliani and Sutch (1966) has been applied to money markets (e.g., Park & Reinganum, 1986; Ogden, 1987; Musto, 1997). By forcing CCPs to invest in given assets, we determine a source of preferred habitat affecting money market rates.

repositories. Among other things, it introduced clearing requirements for OTC derivatives and uniform standards for the operation of European CCPs. Of particular interest are the requirements concerning CCP's handling of the cash collected daily as part of their risk management procedures in the form of initial margin and default fund contributions. They require CCPs to hold at most 5% on average on unsecured deposits, which protects them against counterparty risk. In practice, complying with this regulation requires CCPs to invest their cash daily into reverse repos, government bonds, and when available, central bank deposits.[14]

CCPs collect initial margin daily (or sometimes intraday) as a protection against counterparty risk. Initial margin calculations are risk-based reflecting the size and the riskiness of clearing members' portfolios. Data from public disclosures indicate that about 40% of the initial margin collected by the top 10 European CCPs in 2016 was in cash. This share remained essentially constant from 2016 to 2019 suggesting that unconventional policies including the QE and central bank liquidity provisions have not led banks to pledge more cash as collateral. The cash that needs to be invested daily by CCPs is considerable. For instance, the total cash held daily by the top 10 European CCPs in 2016 exceeded EUR140 billion.[15]

The enormous amount of cash held by CCPs reflects the sheer size of the markets they clear and the mandatory central clearing of standardised OTC derivatives first introduced in the US and EU in 2013 and 2016, re-

[14]See the Article 47 of EMIR and Commission Delegated Regulation (EU) No 153/2013 (EC, 2013, p. 63, Article45). The latter says that"where cash is maintained overnight [...] not less than 95% of such cash,calculated over an average period of one calendar month, shall be deposited through arrangements that ensure the collateralisation of the cash with highly liquid financial instruments [...]."

[15]The numbers in this paragraph are based on the CPMI-IOSCO Public Quantitative Disclosures by European CCPs at the end of the first quarter of 2016. See `http://www.eachccp.eu/cpmi-iosco-public-quantitative-disclosure/`.

spectively. At the end of 2016, the outstanding notional in OTC derivatives market amounted to $544 trillion, of which 61% were centrally cleared for interest rate derivatives, 28% for CDS, and minuscule for FX, commodity and equity derivatives (e.g., FSB, 2017a, 2017b). As central clearing mandates are phased-in, the proportion of central clearing segment, and consequently the size of CCP investment, is expected to continue to grow.

Our main interest lies in the CCPs' investment in reverse repos. We consider this investment as exogenous to the repo market since it is driven by the need for regulatory compliance with EMIR. If it was not for EMIR, CCPs would have no trading activity in the reverse repo market. Note that CCPs also have no control of the size of CCP investment, which is solely driven by the margin posted by clearing members. Margin tends to increase with portfolio volatility and the net position of a clearing member against the CCP. As discussed earlier, the composition of margin has been fairly stable between 2016 and 2019, with cash accounting for about 40% with the rest being securities. Furthermore, clearing members have no incentive to deposit excess cash with the CCP, as there is typically a charge, that is a spread on the overnight benchmark index, for example the EONIA for Euro-denominated cash. Consequently, we regard the size of CCP investment in reverse repos as mechanically and exogenously determined.

The CCPs have the option to substitute reverse repos with other safe assets, for example government bonds. However, we think it an unlike option for two reasons. First, purchasing individual securities (specific ISIN) from the illiquid bond markets is costlier than obtaining general collateral (GC) in a reverse repo. Second, EMIR (EC, 2013, p. 74) requires that the average time-to-maturity of CCP investment portfolios does not exceed two years, an important constraint for purchasing individual bonds. Nonetheless, to err on the side of caution, all our regressions include the CCP bond investments as a control variable.

Another option for CCPs is to deposit cash at central banks. However, this option is not always available, while when it exists it can come with strict requirements. This is particularly the case with the CCPs in our sample. The Sterling Monetary Framework is built around using a reserves averaging system. Participants set a target for the average reserves they will hold over the next maintenance period. Holding average reserves outside a narrow range around this target attracts a charge (Bank of England, 2015, pp. 4-5). Although the reserves averaging scheme was suspended for banks in 2009, it still applies to UK CCPs that must hold daily average reserves between 99% and 101% of the said target. Missing the target gives rise to a hefty charge of 200 basis points (Bank of England, 2019, p. 7). Given the volatile nature of initial margin and the cash held by CCPs, the use of central banks deposits by UK CCPs as a mean to comply to the EMIR requirement is rather restrictive.

Hence, in practise the CCPs in our sample comply with the EMIR by investing in the reverse repo market. More generally, in Europe the proportion of CCP investment in reverse repos varies across CCPs.[16] Even so, the aggregate CCP investment in reverse repos is substantial. Public data from the CPMI-IOSCO quantitative disclosures of the top 10 EU CCPs in the first quarter of 2016 suggest that their aggregate daily investment in reverse repos was in excess of EUR60 billion or about 45% of the cash held by these CCPs.

[16] For example, EuroCCP (2018) reports that 100% of cash received from clearing members is deposited with commercial banks over reverse repos. Conversely, Eurex Clearing deposits the vast majority of its cash with the central bank.

2.2 Basel III

The Basel III framework,announced in 2010, was developed by the Basel Committee on Banking Supervision (BCBS) aiming at strengthening the regulatory framework for banks. Capital requirements are central to Basel III. In particular, the leverage ratio (i.e., the ratio of Tier 1 capital to total exposures) was introduced as a non-risk weighted capital ratio in an attempt to limit the overly building-up of leverage in banks' balance sheet.

The BCBS required banks to report their leverage ratio to national supervisors from 1 January 2013, followed by a public disclosure requirement from 1 January 2015. However, the leverage ratio was only scheduled to become mandatory with a minimum ratio of 3% in January 2018. The BCBS reporting requirement has been implemented differently across jurisdictions. In the European Union, banks report their leverage ratio based on quarter-end figures. Other jurisdictions require leverage ratio reporting based on averaging. For example, in the UK, from January 2016 onwards, the seven larger UK banks were required to report quarterly the average of on-balance sheet assets on the last day of each month during the reference quarter. From January 2017 onwards, this rule changed to daily averaging.[17]

The leverage ratio reporting requirements brought about the practice of window-dressing, i.e., the adjustment of banks' balance sheets around the regulatory reporting dates, mainly at year-and quarter-ends (BIS, 2018). We exploit this practice below to identify banks' balance sheet constraints (i.e. demand effects).

In Europe, the treatment of repo market exposures in the leverage ratio calculation is asymmetric. As illustrated in Figure 2, repo borrowers retain

[17] In contrast, other regulated banks (e.g., smaller UK banks or subsidiaries of foreign banks) have continued to report based on end-of-quarter figures.

the collateral on their balance sheet, as they are already committed to repurchasing the asset in the future, and are therefore exposed to the risk of the collateral. As a result, the cash borrowed and entered on the asset side is balanced by an equally sized position on the liability side. Hence, a repo transaction expands the balance sheet thus reducing the leverage ratio. Conversely, reverse repos do not enter the leverage ratio calculation because the buyer is not exposed to the risk of collateral (except in the case of a default). Consequently, the collateral is not added as an asset in the bank's balance sheet, while the cash received is removed from the asset side and replaced by a repo loan receivable.

[Insert Figure 2 here.]

As a result, banks' intermediation involving repo demand (as opposed to repo supply, or reverse repos) is constrained by the leverage ratio (see Domanski, Gambacorta, and Picillo (2015) andDuffie (2016)). This applies in particular to global systemically important banks (G-SIB) that receive a capital surcharge in addition to the minimum leverage ratio. We expect the impact of the leverage ratio in the repo market to grow around the reporting end-of-quarter dates (Munyan (2015)), a manifestation of the decreasing demand for repos when the leverage ratio bites banks' balance sheet the most.

3 Data

Our research relies on two main datasets. The first captures repo rates and volumes in the interbank Euro and Sterling repo market. The second represents clearing house infrastructure. The intersection of both datasets defines our sample period, starting on 4 November 2013 and ending on 29 December 2017 (i.e., a total of 1065 business days).

3.1 Repo Interbank Market

Repos are the most used contract in the interbank credit market (ECB, 2015, p. 4). Our repo dataset consists of the near-total universe of all electronically traded repo transactions in Euro and Sterling. It is obtained from the three most important repo trading platforms in Europe: BrokerTec, Eurex Repo, and MTS Repo. Every transaction includes the following information: the repo rate; the currency; the cash amount; the trade-, purchase-, and repurchase day; the collateral's ISIN or country of origin; whether the repo was initiated by the cash borrower or lender; identifier of parties involved in a contract; and whether the repo is cleared by a CCP. We removed by hand 12 observations with obvious faulty data.

Table 1 shows a breakdown of the dataset by trading venue, clearing, currency, the collateral's country of origin (the first two letters of ISIN) and maturity. Two remarks are in order here. First, volumes in Sterling have been converted to Euros, at an exchange rate of 1.12 EUR/GBP (only for the purpose of this table). Second, a repo is collateralised with GB collateral if and only if it is denominated in Sterling. Very few transactions violated this rule and have been discarded to simplify the analysis. In contrast, the Euro repo market collateral is quite diverse since the majority of collateral are Euro Area government bonds.

[Insert Table 1 here.]

The table reveals that the vast majority of repos in our sample are centrally cleared with a one-day maturity. As a CCP assumes all counterparty credit risk, these trading venues are able to provide fully anonymous repo trading. This makes the electronically traded repo market an ideal research ground for short-term interest rates as it naturally excludes many confounding factors.

For example, every trader faces the same counterparty credit risk as exposure is only to the CCP. Similarly, relationship trading and asymmetric information issues (e.g. about counterparty credit risk) are not important as all parties see the same anonymised central limit order book and cannot select specific counterparties.

After grouping repo transactions by tenor and collateral country, we focus on the most liquid groups in the interbank market. This produces six countries and four tenors (ON, TN, SN, S1W).[18] Three country-tenor combinations needed to be removed as they are very infrequently traded, and hence introduce a lot of missing values in our time series. The resulting panel consists of 21 segments, of which 17 (4) have a one-day (one-week) tenor. As the composition of CCP investment positions is confidential, we cannot disclose which countries were included.

For every segment, we compute daily volume-weighted average repo rates and "aggressive" (i.e., by means of market orders[19]) borrowing and lending volumes. The difference between aggressive borrowing and lending volumes defines the order flow.

Figure 1 displays the evolution of European repo rates. Three facts are worth noting: First, the repo market is characterized by two regimes. While in the first part of the sample period Euro and Sterling repo rates tended to follow the respective central bank deposit rate, in the second part they tended to trade *below* those rates. Second, the cross-sectional dispersion of Euro repo rates has increased significantly in recent years. Higher quality collateral,

[18] A repo tenor consists of two parts. The first denotes the forward period between trade and settlement (O=Overnight, T=Tomorrow, S=Spot (2 days)), whereas the second denotes the period between settlement and maturity (N=next (1 day), 1W (5 business days)).

[19] We are unable to measure liquidity provision using (non-aggressive) limit orders, as our dataset contains no order book.

such as German or French government bonds, exhibit much lower rates than relatively less safe collateral. Third, strong seasonalities are evident at the month-end (quarter-end) and entail lower rates and larger rate dispersion.

The first pattern, i.e. interbank repo rates trading below the central bank deposit rate, may seem puzzling as banks could just borrow cash in the repo market and then deposit it with the respective central bank to make a safe profit. A sufficient quantity of this near-arbitrage trading strategy would keep interbank rates strictly tied to the central bank deposit rate.[20] The second pattern indicating wider cross-sectional dispersion of repo rates suggests different "convenience yields" (Krishnamurthy & Vissing-Jorgensen, 2012) embedded in repos and it can lead to passthrough inefficiency of monetary policies (Duffie & Krishnamurthy, 2016, p. 1). The third (seasonal) patterns coincide with regulatory reporting periods. However, how exactly regulations affect repo rates is an open question, which we analyse in the remainder of this paper.

In the remainder of this paper, we use the spread between repo rates and the central bank deposit rate (i.e. the ECB and the Bank of England deposit rates for Euro and Sterling repos, respectively). We do so for two reasons. First, we observe that repo rates exhibit some degree of persistence and trend. Taking the spread over the deposit rate ensures stationarity. Second, the spread has an economically meaningful interpretation measuring how far the cost of private liquidity (represented by repos) is from the public liquidity rate (represented by the central bank deposit rate). In a stable monetary regime, they should converge. The Levin-Lin-Chu (LLC) test for panel data and the Augmented-Dickey-Fuller (ADF) test for univariate data strongly reject unit roots at the 1% significance level for both repo spreads to deposit rates and

[20] This can be considered near-arbitrage rather than pure arbitrage as a bank needs to hold and pledge collateral to enter the repo position.

for interbank order flows.

3.2 CCP Investments

Our analysis uses daily investments from EMIR-regulated clearing infrastructures as reported to the Bank of England between November 2013 and December 2017. Although our quantities are representative of the UK CCP market, confidentiality reasons prevent us from disclosing the clearing houses in our analysis. Nor are we able to divulge whether their investment activities stem merely from some or rather from all of their clearing services.

The data contain the reverse repo and bond purchase volumes that the supervised clearing houses settle every day to comply with the EMIR rule (see section 2.1). These volumes are split by the collateral's country of origin. Although they are very granular, these reports do not distinguish between tenors. Hence, we use the same volumes across all tenors of a given country in the panel cross-section.

To protect the confidentiality of this dataset, we standardise the time series by subtracting the mean and by dividing by the standard deviation of the total reverse repo lending (bond purchase) volume across countries. The units of reverse repo (bonds) investments are therefore standard deviations of total reverse repo (bonds) investments. This holds the relative sizes between countries constant and does not change the sign or significance of the regression estimates presented below. It does, however, allow us to show the economic significance of an hypothetical investment volume without disclosing its actual size.

Importantly, these reverse repo loans are conducted over-the-counter (OTC) and not in the repo interbank market itself. However, most counterparties at the same time participate in the interbank market. This is especially relevant for identifying the effects of balance sheet constraints. In the absence of multilateral netting mechanisms, which exist in the centrally cleared interbank market, and with no room for bilateral netting because CCPs almost exclusively lend, these reverse repo investments must end up on the counterparties' balance sheets and lower their leverage ratios. Hence, this setting enables us to establish the natural transmission from regulation onto interbank rates through OTC intermediation.

The LLC test rejects a unit-root for CCPs' reverse repo investments, although we find that repo investments with one particular country's collateral are only weakly stationary. A removal of this country leads to rejecting of a unit-root at the 1% significance level. On the other hand, a unit-root in CCPs' bond investments cannot be rejected, likely due to a some discrete jumps in investment volumes. We do appropriate robustness checks in section 6.3 to verify that inclusion of this country and the bond investments control variable does not lead to spurious correlations in our results. We find that, if anything, inclusion works against our results.

3.3 Other Data

In addition to repo market and clearing infrastructure data, we consider foreign exchange markets, general volatility, as well as quantitative easing. More specifically, we add the *covered interest rate parity basis* (CIP), the *Euro 50 STOXX volatility index* (VSTOXX), and the share of purchase-eligible government debt bought through the *public sector purchasing programme* (PSPP) as controls to our regressions.

The CIP basis is given by

$$CIP_{i,t} = r^{USD}_{t,t+n(i)} - r^{ccy(i)}_{t,t+n(i)} + \frac{252}{n(i)} \left(f^{USD,ccy(i)}_{t,t+n(i)} - s^{USD,ccy(i)}_{t} \right)$$

where t denotes the day and i denotes the panel segment. $n(i)$ equals the tenor of the repo segment in days (i.e., either 1 or 5), whereas $ccy(i)$ denotes its currency (i.e., either EUR or GBP). Variable r denotes the unsecured LIBOR interest rate (in logs), which were downloaded from the Federal Reserve Economic Data (FRED) website.[21] Variables s and f denote the spot and forward exchange rates (in logs) between USD and $ccy(i)$, given in units of $ccy(i)$ per USD. The spot and forward rates were downloaded from Bloomberg.

We include the CIP basis as a control because interest rates and FX markets are closely interrelated. Depending upon exchange rates, a bank facing margin call might find it more worthwhile to execute a carry-trade, to lend in the foreign currency's repo market to obtain collateral and to deliver said collateral to satisfy the margin call rather than to simply deliver domestic collateral already in its possession. Hence, FX rates influence which collateral is *cheapest-to-deliver* and therefore affect repo demand and supply. Furthermore, CIP arbitrageurs need to borrow and lend cash to create synthetic interest rates. For CIP violations at the short end of the yield curve, one way to eliminate credit risk and the dwindling liquidity associated with Libor-based CIP is to use lending and borrowing rates from the repo markets (Du et al., 2018, p. 930). Hence, short-term CIP arbitraging affects repo demand and supply. We control for the CIP basis as it exhibits profound seasonalities around quarter-ends when leverage ratios must be reported (Du et al., 2018, p. 940).

Furthermore, we control for overall financial markets volatility and margin procyclicality by including the VSTOXX measuring the EURO STOXX 50 implied volatility index.[22] Being an important determinant of how much

[21] `https://fred.stlouisfed.org/`

[22] The VSTOXX is similar to CBOE VIX and the data are accessible in Bloomberg. Using VIX instead of VSTOXX, we obtain similar results.

margin must be deposited at CCPs for a given trade, volatility can influence how much cash CCPs must invest in reverse repos and government bonds. As margin requirements in the European interbank repo market are recalculated infrequently or are pre-established (e.g., Mancini et al., 2016; Nyborg, 2016), we control for this variable with a lag of one day.

Finally, we also control for the ECB's public sector purchase programme (PSPP) as it constitutes an alternative explanation for the repo rates patterns shown in figure 1 (e.g., Arrata et al., in press; Pelizzon et al., 2018). To capture the size of PSPP operations, we compute the percent-share of a outstanding debt that has been purchased by the ECB through PSPP, i.e.

$$PSPP_{i,t} = \frac{Purchases_{i,t}}{Outstanding_{i,t}} \cdot 100$$

where $Purchases_{i,t}$ denotes the cumulative PSPP purchases of country i's government debt until day t, and $Outstanding_{i,t}$ denotes that country's total outstanding debt[23] eligible for PSPP purchases. To construct $Purchases_{i,t}$, we start out with the monthly breakdown of PSPP purchases.[24] Using the weekly time series of "Securities held for monetary policy purposes" contained in the ECB's weekly financial statements, we interpolate $Purchases_{i,t}$ to weekly frequency.[25] The data source for weekly values of $Outstanding_{i,t}$ is the ECB's Eligible Assets database.[26] Finally, we compute weekly values of $PSPP_{i,t}$ and interpolate it linearly to daily frequency. As this variable is clearly not stationary, we include the day-to-day change $\Delta PSPP_{i,t}$ in the regressions.

[23]We exclude inflation-linked debt for simplicity and because it is less relevant for the repo market.

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

[25]`https://www.ecb.europa.eu/press/pr/wfs/2019/html/index.en.html`

[26]`https://mfi-assets.ecb.int/queryEa.htm`, although one would have had to download the data regularly since 2015. We are grateful for the ECB's assistance.

4 Supply Effects

Methods

The supply hypothesis puts forward that the regulatory-driven supply of repos (demand of collateral) by clearing houses decreases short-term rates. To test it, we use a standard panel regression setup. Equation (1) outlines the baseline regression equation used and adapted in subsequent sections.

$$\begin{aligned} Rate_{i,t} = \alpha \cdot Rate_{i,t-1} + \gamma \cdot Orderflow_{i,t} + \lambda \cdot Reverse_{i,t} \\ + \mu_i + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \epsilon_{i,t} \end{aligned} \tag{1}$$

The i index denotes the cross-section of the panel, while μ_i denotes the standard fixed-effects dummies, one for every i. The response variable $Rate_{i,t}$ denotes the spread between volume-weighted average interbank repo rates and the central bank deposit rate.

We add the first lag of the dependent variable as a control to control for any persistence in the repo rates variables.[27] To account for endogenous demand and supply within the interbank market, we add interbank order flow as an explanatory variable. When repo rates are regressed on it, the estimated coefficient γ captures the order flow price impact within the interbank repo market.

The $Reverse_{i,t}$ variable contains the aggregate and standardised CCP reverse repo investment volume. The coefficient λ is our main coefficient of interest, as it captures the impact of CCP reverse repo investments in the

[27] Including lagged values of the dependent variable might introduce Nickell's (1981) bias. However, this is typically the case for panel regressions with an arbitrarily large cross-section but only a few time periods. As the number of time periods grows, the bias approaches zero. Given that our data feature a long time-series of 1065 business days and only 21 cross-sectional segments, we believe that our results do not suffer from this bias and are consistent

OTC market on interbank repo rates. It is worth stressing that $Reverse_{i,t}$ can be interpreted as the order flow (although standardised and with a negative sign) stemming from the CCPs cash lending in the OTC segment. Hence, we occasionally refer to λ as the *price impact* of the CCP reverse repo investments. We do so, although the CCPs trade OTC while the interbank market is based on centrally cleared electronic limit order books. Thus, it is important to remember that λ captures spillover effects from the OTC (bilateral) segment to interbank (centrally cleared) segment of the repo market. An alternative way of considering CCPs' supply of repos is as if it were an instrumental variable (IV) measuring exogenous supply to the interbank repo market. In fact, CCPs' supply is (a) set by regulation, (b) determined by the amount of cash accumulated on CCPs' margin accounts, and (c) conducted in the *OTC segment*, while we analyse the impact on *interbank* market.

The $\boldsymbol{X}_{i,t}$ vector contains our control variables, which we motivate next.

$$\boldsymbol{X}_{i,t} = \begin{bmatrix} Bonds_{i,t} \\ CIP_{i,t} \\ VSTOXX_{t-1} \\ \Delta PSPP_{i,t} \end{bmatrix}$$

First, we add CCPs' aggregate and standardised outright government *bonds* purchases as they can indirectly lower repo rates through "specialness", that is, collateral becomes scarce (Duffie, 1996). Hence, if $Reverse_{i,t}$ and $Bonds_{i,t}$ are correlated, excluding $Bonds_{i,t}$ from the regression would lead to an omitted variable bias in the coefficient λ. Second, we control for the overall financial markets situation by adding the CIP basis and volatility index. The former influences repo market supply and demand, whereas the latter influences the amount of cash deposited on CCPs' margin accounts (see section 3.3 for details). Finally, we control for possible effects such as collateral scarcity stemming from Quantitative Easing. More specifically, we add the percent-share of countries' outstanding and eligible government debt purchased through ECB's PSPP to the controls.

To be conservative, we exclude the last day of each quarter from the regression as extreme seasonalities affect interbank repo rates, trading volume, and the CIP basis. This also excludes or reduces confounding factors apart from leverage ratio reporting that might change a bank's repo trading behaviour during these days (BIS, 2017, p. 38). It is worth stressing that excluding the very last days at quarter-ends does not qualitatively change our main results and do not weaken our diff-in-diff identification strategy (see section 5) because all repo tenors under scrutiny are equally affected during these days.

Consistent with the supply hypothesis, a negative λ indicates that in a non-fully-elastic environment, the increasing supply from CCP reverse repo investments lowers rates (while holding the repo demand constant).

Results

Table 2 shows the main findings. Two considerations arise: First, the estimates of the price impact of CCP reverse repo investments are significantly negative supporting the supply hypothesis. Every standard deviation increase in reverse repo investments lowers interbank repo rates from the central bank deposit rate by 1.559 basepoints. The estimated supply (negative) impact from CCP reverse repos remains significant after adding the control variables.

Second, all estimated coefficients of the control variables exhibit the expected signs but are not always statistically significant. Specifically, the estimates of the price impact of the interbank order flow is positive and significant, as postulated by microstructure theories. CCPs' bond purchases do not significantly affect the repo rates suggesting that specialness has only an indirect effect in the regulatory transmission mechanism. On the other hand, the significance of the CIP estimate confirms the important connection between short-term interest rates and FX rates. Also, the positive coefficient of the volatility variable points to the tendency of funding cost to increase in stressed market conditions inducing some margin procyclicality. Unconventional monetary policies do not seem to affect our results.

Overall, these results are consistent with the idea that CCP reverse repo investments due to new regulation drags down repo rates below the central bank's deposit rate. It also highlights that rather than being market neutral, the purchase of safe assets induced by the EMIR rule seems to contribute to their scarcity.

[Insert Table 2 here.]

5 Demand Effects

Methods

Our regression design has so far aimed to identify a causal supply effect of EMIR regulations on the interbank repo market. Next, we describe how we augment the regression design to identify the demand effect stemming from the Basel III leverage ratio.

As outlined in section 2.2, entering a repo contract (i.e., borrowing cash) extends a bank's balance sheet, and hence lowers the leverage ratio, whereas entering a reverse repo contract does not. Thus, the repo accounting practice induces banks to cut back repo positions to increase their leverage ratios while limiting reverse repo positions cannot be used to improve the leverage ratio. It is therefore fair to assume that implementing leverage ratio regulation depresses repo demand, but not repo supply.

The shape of the repo demand curve can be investigated by exploiting exogenous variation in repo supply. CCPs' reverse repo investment can serve this purpose as it is determined by new regulation (see section 2.1). If repo demand falls when Basel III's leverage ratio is binding, a given increase in repo supply should lead to a larger drop in repo rates. This means that the negative price impact of reverse repos becomes more severe with falling repo demand. This identification strategy implicitly assumes that repo supply follows the same systematic patterns both outside and inside the regulatory reporting period. Thus, it does not change due to leverage ratio concerns.

Therefore, we test whether repo demand falls by checking whether the negative price impact of CCPs' reverse repo investments becomes stronger (i.e., the coefficient λ in (1)). We employ a difference-in-differences design to causally attribute these changes to leverage ratio regulation. Whether a repo position ends up on the balance sheet and worsens a bank's leverage ratio depends on its tenor and on leverage ratio disclosure schedule. This has been documented by Du et al. (2018, pp. 940–944) for foreign exchange derivatives: They show that violations of the covered interest rate parity increase when leverage ratios must be disclosed to authorities. However, as most European authorities only ask for a snapshot of the balance sheet on the last day of the quarter, only contracts that have not yet matured will be affected by leverage ratio regulations. For example, a one-week forward position traded on 1 March will not affect the balance sheet on 31 March, when the leverage ratio must be reported. However, a one-month forward position traded on the same day will end up on the balance sheet and affected the leverage ratio regulation. Therefore, CIP violations involving one-month forwards will be larger.

Analysing one-day and one-week tenors enables us to exploit the same differences in the repo market (see figure 3). A one-week repo (given by repos with a spot-one-week tenor in our dataset) stays on the balance sheet for five business days, starting on the settlement date. In contrast, a one-day repo (overnight, tomorrow-next and spot-next) enters the balance sheet on the settlement day only as it matures and will be unwound the following morning. Hence, during the four days before the last day of the quarter, one-week repos are affected by leverage ratio regulation whereas 1-day repos are not. If repo demand is affected by leverage ratio regulations, we expect the price impact of CCP reverse repo investments on one-week repos to become more negative during those four days. In contrast, the price impact on one-day repos is not expected to change during this time period. Hence, we compute the difference in price impacts between one-day and one-week repos and test whether it changes during the last four days of the quarter. A change in this difference should be caused by falling borrowing demand due to leverage ratio regulation.

[Insert Figure 3 here.]

We introduce two additional dummy variables into regression (1) to estimate this change of differences. Variable $1W_i$ equals 1 iff. the tenor of repo contract i is spot-1-week (S1W). Similarly, $BeforeEoQ_t$ equals 1 iff. day t is 1-4 days before the end of a quarter. To obtain the difference-in-differences estimator, we interact these dummies with CCP reverse repo investments

$Reverse_{i,t}$.

$$\begin{aligned} Rate_{i,t} = \alpha \cdot Rate_{i,t-1} + \gamma \cdot Orderflow_{i,t} + \lambda_1 \cdot Reverse_{i,t} \\ + \lambda_2 \cdot 1W_i \cdot Reverse_{i,t} + \lambda_3 \cdot BeforeEoQ_t \cdot Reverse_{i,t} \\ + \lambda_4 \cdot \ 1W_i \cdot BeforeEoQ_t \cdot Reverse_{i,t} \\ + \mu_i + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \eta \cdot BeforeEoQ_t + \epsilon_{i,t} \end{aligned} \tag{2}$$

In this regression, λ_1 captures the impact on one-day repos during normal times (i.e., not before the end-of-quarter), whereas λ_2 represents an additional impact on one-week repos during normal times and λ_3 represents an additional impact on one-day repos before the end of the quarter. Thus, λ_4 is the difference-in-differences estimator and captures the additional impact on one-week repos before the end of the quarter. We also add the uninteracted $BeforeEoQ_t$ term to account for overall differences in the level of $Rate_{i,t}$ before the end of the quarter. Note that we do not explicitly add the uninteracted $1W_i$ term because it is collinear with and hence absorbed into the fixed effects μ_i.

The main variable of interest to test the demand hypothesis is λ_4 as it captures an additional price impact on repos that end up on the balance sheet during leverage-ratio reporting days. If leverage-constrained dealers or banks cater more CCPs' reverse repo orders ($Reverse_{i,t}$) in the OTC segment, they have less balance sheet space left to borrow or intermediate in the interbank market. Hence, if leverage ratio regulation lowers demand for repos, then the price impact of CCP reverse repos on interbank repos ought to be even more negative ($\lambda_4 < 0$) for repo contracts that contribute to the leverage ratio.

The λ_3 coefficient is of secondary interest because it captures an additional price impact on one-day repos during the last days before the end-of-quarter.

If our assumptions hold, then λ_3 ought to be close to zero as these one-day repos mature before the leverage ratio must be disclosed.

Results

Table 3 shows the estimates from the difference-in-differences regression equation (2), which isolates the causal effect of leverage ratio reporting on repo rates. During the last four days before the last day of the quarter (when leverage ratios must be calculated and reported), the difference between the price impacts of one-day and one-week repos changes significantly. While the former additional price impact is statistically insignificant, the latter suffer from an additional staggering price impact of -26.383 bp per standard deviation (with a P-value of 5.2%). Given that repo supply is not affected by leverage ratio concerns, a stronger price impact must be caused by decreasing repo demand. More specifically, the slope of the demand curve must become more negative, which is identified by this additional price impact. On the other hand, the inward shift of the demand curve is captured by the coefficient of $BeforeEoQ_t \cdot 1W_i$ which is also significantly negative.[28] Overall, our results suggest that the demand for repos that end up on the balance sheet during the end-of-quarter falls. In contrast, the demand for repos not affected by the leverage ratio regulation remains unchanged.

[Insert Table 3 here.]

6 Additional Tests

So far, we have showed that EMIR and Basel III regulations decrease short-term rates. But how does the transmission mechanism work? To understand it

[28] Although our results are robust to a potential shift in the demand curve, we do not claim to properly identify it.

better, we extend our analysis by addressing two issues: (i) whether regulation induces rate dispersion across repos, and (ii) whether it affects borrowing and lending behaviour of individual banks. Answering these questions should shed light on whether repos and banks are equally affected by regulations, and if not, why.

6.1 Rate Dispersion

Methods

Regarding rate dispersion, we investigate whether CCP reverse repo investments drive a wedge between two countries' interbank repo rates, which has widened since 2015 as illustrated in in Figure 1. If we do not find any significant effects on repo rate spreads, repo contracts should be equally affected by the CCP reverse repo investments. Therefore, the negative impact on the upper and lower components of the spread offset each other. This result would square well with a fully integrated repo market, in which the price impact caused by the CCP cash supply (purchase of collateral assets) uniformly spillover across its segments. Such a pervasive effect is plausible as the leverage ratio is an unweighted risk-measure and hence does not differentiate between repos with different collateral.

Instead, an uneven impact of regulation across repo contracts can be explained from two perspectives: First, from the standpoint of the safe asset literature repos are near-money assets providing safety and liquidity benefits that give rise to a convenience yield. The convenience yield of an asset increases with the asset scarcity (Krishnamurthy & Vissing-Jorgensen, 2012) and differences in convenience yields can explain cross-sectional and temporal variations in money market instruments (e.g. Bartolini, Hilton, Sundaresan,

& Tonetti, 2011). Thus, the safe asset explanation for larger repo spreads is the impact of CCPs purchases of collateral assets on convenience yields through (collateral) asset scarcity. The second explanation for an increasing repo spread is the balance-sheet-constrainedness effect, that is, a regulatory cost involving a simultaneous position in a repo borrowing at a low rate and a reverse repo lending at a high rate. Unless netted, the repo leg of this position expands the balance sheet creating regulatory costs decreasing the repo rate (see discussion in Section 5)

We use the spread between a "quote" country q and a "base" country b as a measure of dispersion. The panel cross-section index i then corresponds to a triplet (q, b, m), where m is the tenor of the repo segment. Note that we fix the base b to the country exhibiting the *lowest* repo rates. From the safe asset perceptive, the repo with the lowest (highest) rate provides the largest (smallest) convenience yield. This approach ensures $Spread_{i,t}$ to be positive. Thus, every i corresponds to one (q, m)-combination.

$$Spread_{i,t} = Rate_{q,m,t} - Rate_{b,m,t}$$

We exclude Sterling repos from these regressions to ensure that we only take spreads between Euro repos. Substituting the rates regression equation (1) with this spread, as well as rearranging and simplifying terms, produces our first dispersion panel regression equation.

$$\begin{aligned} Spread_{i,t} = \alpha \cdot Spread_{i,t-1} + \mu_i + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \epsilon_{i,t} \\ + \gamma_1 \cdot \overbrace{Orderflow_{q,t}}^{QuoteOrderflow_{i,t}} + \gamma_2 \cdot \overbrace{Orderflow_{b,t}}^{BaseOrderflow_{i,t}} \\ + \lambda_1 \cdot \overbrace{Reverse_{q,t}}^{QuoteReverse_{i,t}} + \lambda_2 \cdot \overbrace{Reverse_{b,t}}^{BaseReverse_{i,t}} \end{aligned} \tag{3}$$

Analogously, the controls vector must be expanded with both countries' CCP bond purchases and PSPP purchases as follows:

$$\boldsymbol{X}_{i,t} = \begin{bmatrix} QuoteBonds_{i,t} \\ BaseBonds_{i,t} \\ CIP_{EUR,t} \\ VIX_{t-1} \\ \Delta QuotePSPP_{i,t} \\ \Delta BasePSPP_{i,t} \end{bmatrix}$$

The coefficients λ_1 and λ_2 capture the impact of CCP reverse repo investments on the repo rate spread between countries q and b. Given that the supply hypothesis implies a negative price impact of every country's investments on its own repo rate, we should expect λ_1 to be negative as reverse repo investments lower the spread's upper component. Conversely we should expect λ_2 to be positive as reverse repo investments decrease its lower component.

In addition to the separate base and quote effects, we estimate overall impact. Specifically, we take the sum over all reverse repo investments, that is, $TotalReverse_t = \sum_i Reverse_{i,t}$, and regress spreads on total reverse repo investments.

$$Spread_{i,t} = \lambda \cdot TotalReverse_t + \dots \tag{4}$$

Here the interpretation of λ is unambiguous. If λ is positive, CCPs' reverse repo investments increase the dispersion of Euro repo rates. Finally, we repeat the difference-in-differences regression (2) for spreads instead of rates.

$$\begin{aligned} Spread_{i,t} = \lambda_1 \cdot TotalReverse_t + \lambda_2 \cdot 1W_i \cdot TotalReverse_t \\ + \lambda_3 \cdot BeforeEoQ_t \cdot TotalReverse_t \\ + \lambda_4 \cdot 1W_i \cdot BeforeEoQ_t \cdot TotalReverse_t \\ + \eta \cdot BeforeEoQ_t + \dots \end{aligned} \tag{5}$$

As previously, $1W_i$ is 1 iff. the spread is taken between one-week repos.[29] If leverage ratio regulation does cause increased rates dispersion in the Euro repo market, then we expect λ_4 to be positive.

Results

Table 4 delivers two main results. First, CCPs' reverse repo investments widens repo rates dispersion. When we analyse the separate impact of CCPs' reverse repo investment volumes of the quote country and base country (see regression (7)), we find that the rate repo spread increase is mostly driven by the base country impact (i.e. the low-rate leg). For instance, we find that a hypothetical CCP purchase of base country's collateral assets increases the spread by about 5.414 bp per standard deviation of investments. Conversely, investments in the quote country (i.e. high-rate leg) have no significant effect. These findings provide empirical support to the safe asset hypothesis, that is, the regulatory-driven collateral demand of the clearing infrastructure increases the convenience yield of purchased assets.

Turning to the regression results (9), we find clear evidence that total reverse repo investments due to EMIR increase rate dispersion in the Euro repo market. For instance, a one standard deviation increase in total reverse repo

[29] As before, the uninteracted $1W_i$ term is omitted because it is collinear with the panel fixed-effects.

investments, regardless of country, increases rate dispersion by 3.667 bp. This picture is consistent with the balance-sheet-constrainedness explanation, that is, a simultaneous repo and reverse-repo position requires balance sheet space and hence creates regulatory costs due to leverage ratio regulation. Employing the same diff-in-diff setting as in (6), we also find that repos that end up on the balance sheet during reporting days exhibit an additional increase in rate dispersion of 21.302 bp per standard deviation of reverse repo investments. The drop in demand due to leverage ratio regulation therefore increases rate dispersion and exacerbates the regulatory impact of repo supply due to EMIR.

[Insert Table 4 here.]

6.2 Individual Behaviours

In this section, we investigate the transmission mechanism of regulations through the lens of the bank's individual behaviour. We do so by analysing how individual banks borrow and lend in the interbank market, and whether their behaviour is different when they enter a bilateral repo with CCPs in the OTC segment.

Entering a bilateral repo with a CCP has three main effects for a bank: a cash surplus, a shortage of HQLA assets, and an expansion of the balance sheet. Given the related inventory and regulatory costs (see the discussion in section 2.2), that bank has an incentive to offset cash and asset imbalances in the interbank market. Thus, two testable hypotheses arise: First, banks that have been CCP counterparties should lend more in the interbank market; second, the same banks should borrow less in the interbank market. Furthermore, the balance sheet expansion can induce banks to cut back on liquidity provision (see discussion in section 2.2). This is especially true for unnetted positions as the interbank repo market is centrally cleared thereby offering netting benefits. Then, the third testing hypothesis is that banks that have been CCP counterparties are more reluctant to provide liquidity in the interbank market.

Methods

To analyse individual banks' behaviours in the interbank market, we consider their propensity to lend or borrow cash, and to provide or consume liquidity. As standard in market microstructure, the submission of market and limit orders define the provision and consumption of market liquidity, respectively. Specifically, we divide a bank's[30] daily gross trading volume into four shares: (1) borrowing cash with market orders ("aggressive" borrowing consuming liquidity); (2) borrowing with limit orders ("non-aggressive" borrowing supplying liquidity); (3) lending with market orders (aggressive lending); and (4) lending with limit orders (non-aggressive lending). Let i denote a bank, and let the pair (t, j) denote the j-th transaction on day t. The propensity of bank i to borrow (lend) cash consuming (providing) market liquidity on day t is given by $MarketBorrow_{i,t}$ ($LimitLend_{i,t}$) and defined as follows,

$$MarketBorrow_{i,t} = \frac{\sum_j \mathbf{1}\{Borrower_{t,j} = i \wedge Aggressor_{t,j} = i\} \cdot Volume_{t,j}}{\sum_j Volume_{t,j}}$$

$$LimitLend_{i,t} = \frac{\sum_j \mathbf{1}\{Lender_{t,j} = i \wedge Aggressor_{t,j} \neq i\} \cdot Volume_{t,j}}{\sum_j Volume_{t,j}}$$

[30] The repo data from BrokerTec and Eurex Repo contains anonymized trader IDs that allows us to reconstruct bank's individual trading positions. We identify CCP counterparties by matching BrokerTec (Eurex Repo) transactions to regulatory data from RepoClear (Target2) to obtain actual bank names, and then flagging those banks that borrow from CCPs in the OTC market. Note that we discard repo transactions from MTS Repo (which serves the Italian repo market) for this analysis because neither anonymous IDs nor regulatory data to match transactions against is available.

where $Volume_{t,j}$ denotes the cash amount and $Borrower_{t,j}$ ($Lender_{t,j}$) denotes the identity of the borrower (lender) of transaction (t, j). Finally, $Aggressor_{t,j}$ denotes the identity of the bank initiating the trade with a market order. The two other shares, $MarketLend_{i,t}$ and $LimitBorrow_{i,t}$ are defined analogously.[31] Using the same sample period as before, we obtain panel regressions whose cross sections consist of individual banks (rather than collateral countries, as before). To determine how banks react to CCPs' reverse repos, we regress each share $Y_{i,t}$ on the total volume of CCPs reverse repo investments, ($Reverse_t$), the lagged dependent variable, bank and month fixed effects, as well as a set of controls. To identify different behaviours of banks that are counterparty of CCPs in the OTC segment, we interact $Reverse_t$ with a dummy variable $Counterparty_i$ which is 1 iff. bank i is an OTC counterparty to a CCP. The coefficient λ_2 of this interaction term is our main variable of interest.

$$\begin{aligned} Y_{i,t} = \mu_{1,i} + \mu_{2,month(t)} + \alpha \cdot Y_{i,t-1} + \boldsymbol{\beta}^T \boldsymbol{X}_t \\ + \lambda_1 \cdot Reverse_t + \lambda_2 \cdot Counterparty_i \cdot Reverse_t + \epsilon_{i,t} \end{aligned} \tag{6}$$

A significant positive λ_2 for $Y_{i,t} = MarketLend_{i,t}$ and for $Y_{i,t} = LimitLend_{i,t}$ would support our first hypothesis, that is, CCPs' counterparties lend more in the interbank market. A significant negative λ_2 for $Y_{i,t} = MarketBorrow_{i,t}$ and for $Y_{i,t} = LimitBorrow_{i,t}$ would support the second hypothesis (i.e. CCPs' counterparties borrow less). About the third hypothesis, insignificant λ_2 coefficients associated with $Y_{i,t} = LimitLend_{i,t}$ and $Y_{i,t} = LimitBorrow_{i,t}$ would be in line with a reduced provision of market liquidity by CCPs' counterparties.

[31] Note that either $Lender_{t,j} = Aggressor_{t,j}$ or $Borrower_{t,j} = Aggressor_{t,j}$, and therefore $MarketBorrow_{i,t} + MarketLend_{i,t} + LimitBorrow_{i,t} + LimitLend_{i,t} = 1$ by definition.

The set of controls X_t contains variables that may influence individual trading behaviours.

$$\boldsymbol{X}_t = \begin{bmatrix} Bonds_t \\ OrderShare_t \\ \Delta Rate_t \\ log(Volume_t) \\ EffectiveSpread_t \\ CIP_t \\ VSTOXX_{t-1} \end{bmatrix}$$

In addition to the control variables CIP_t and $VSTOXX_{t-1}$ used in previous regressions[32], we include four market variables that can influence trading behaviours of individual banks: First, to capture overall market imbalances, $OrderShare_t$ is defined as the market order flow divided by gross trading volume. The main idea is that one-sided markets (i.e. $|OrderShare_t|$ is close to one) may affect order aggressiveness. Second, we add the daily repo rate change as a higher (lower) rate might discourage borrowing (lending). Third, (log) total trading volume captures overall activity in the market. Fourth, we estimate effective spreads, as transaction cost is an important dimension of market illiquidity influencing the propensity to trade and to provide further liquidity.[33]

[32] We repeated this analysis by including $\Delta PSPP_t$ as additional control and we obtained insignificant coefficients. We present the regression results without $\Delta PSPP_t$ because its inclusion only raises estimator variance without materially changing the results.

[33] Using trade-by-trade changes in repo rates, we compute the Roll (1984) measure of transaction costs for every collateral and tenor. We also analysed realized volatility as an alternative control variable, but we exclude it from the encompassing model since it is highly correlated with the effective spread.

Results

Table 5 summarises the results. Three key findings stand out: First, the strongest result is obtained for aggressive lending. For every standard deviation increase in CCPs reverse repo lending, banks borrowing from CCPs in the OTC segment lend 0.7% more in the interbank market relative to banks that did not borrow from a CCP. In corroboration of the first hypothesis, this is a sign that banks borrowing from CCPs tend to offload cash surpluses by lending aggressively to other banks in the interbank market.

Second, there is no significant decrease in aggressive borrowing in response to CCP lending. This corroborates our assumption that CCPs' reverse repos only affect repo supply in the interbank market, but not demand.

Third, there is mixed evidence of diminished market liquidity provided by banks entering repos with CCPs. Non-aggressive borrowing of CCP counterparties experiences a drop of 0.5% per standard deviation of CCP reverse repos relative to other banks. This is consistent with banks cutting back on intermediation in response to being leverage-constrained by unnettable[34] repo borrowing positions obtained by serving CCPs reverse repo orders. On the other hand, the impact on non-aggressive lending is insignificant, perhaps because the diminished liquidity provision is offset by a larger pressure to lend in the interbank market.

[Insert Table 5 here.]

6.3 Robustness Tests

We performed a series of robustness analyses proving the correctness of our results. In this section, we report the main robustness checks and shortly

[34]Banks cannot net out their repo borrowing from CCPs because there is no multilateral netting in bilateral agreements and CCPs do not regularly lend.

discuss why some concerns do not apply.

Our findings provide compelling evidence that the supply and demand regulatory effects hold true after controlling for PSPP impact. However, a potential concern is that Quantitative Easing affects the initial margin contributions of clearing members. More specifically, the increased excess liquidity and collateral scarcity originated from the PSPP programme might induce clearing members to deposit more cash than necessary on margin accounts. Consequently, the $Reverse_t$ variable could be influenced by PSPP effects. This is very unlikely because CCPs discourage their members deposit cash collateral (see section 2). Furthermore, there is no suggestive evidence supporting this issue: First, during the subsample period of the PSPP programme, there is no significant change in the composition of margin contributions; second, the correlation between $\Delta PSPP_{i,t}$ and $\Delta Reverse_{i,t}$ is close to zero.

In section 5, we test the demand hypothesis using a difference-in-differences method based on the repo maturity. An alternative approach would be to exploit the differences in disclosure frequency across jurisdictions, in order to separate "treated" traders affected by leverage ratio regulation from "untreated" repo traders. In fact, as discussed (section 2.2) some banks have to report the leverage ratio at the end of every month (in the U.K.), or an average over several month ends. However, this approach has several disadvantages. For instance, many banks in our sample are international entities. Also, many small differences (e.g., time of policy change, disclosure requirements, etc.) exist between countries. Despite these limitations, we test the demand hypothesis by replacing the $BeforeEoQ_t$ dummy (denoting the last four days before the last day of the quarter) with an analogous $BeforeEoM_t$ dummy that is 1 on the last four days before the last day of each *month*. The obtained results are qualitatively identical even if the effect is not as strong. Therefore, we conclude that our results also hold true if balance sheet constraints at the end of each month are considered.

Furthermore, we perform a sub-sampling analysis focusing on general collateral repo rates only as CCPs might prefer to obtain high-quality collateral no matter the exact identity (ISIN) of the collateral security. Despite losing almost 50% of observations, our results stay almost identical and significant in most specifications.[35].

Finally, we address concerns of spurious correlations in our results due to potential non-stationarity in some of our variables. Most importantly, we remove from the cross-section a single country whose CCP reverse repo investments are only weakly stationary. Our results remain virtually unchanged. In addition, we remove some control variables exhibiting strong persistence. More specifically, we remove the $Bonds_{i,t}$ and $VSTOXX_{t-1}$ variables. We find that all estimates remain similar in sign, magnitude and significance. Furthermore, and even though we take first differences, $\Delta PSPP_{i,t}$ still exhibits strong persistence. Excluding it from the regression, as well as replacing it with the change in day-to-day change in Eurosystem excess liquidity[36], does not materially affect our results. Our results also stay significant if we apply all of these changes at the same time. In general, we find that our results remain equally strong or even become stronger (both in magnitude and significance) in each of these robustness checks.

[35] The exception are regressions (3) and (6), which include the full set of controls. There, the coefficient of $Reverse_{i,t}$ obtains a very similar estimate, but is barely significant. Also, the demand effect rises to four times its original size.

[36] Excess liquidity is computed as the aggregate excess reserves defined as Eurosystem's deposits at the ECB deposit facility net of the recourse to the marginal lending facility, plus current account holdings in excess of those contributing to the minimum reserve requirements. We obtain these variables from the ECB statistical data warehouse. Replacing $\Delta PSPP_{i,t}$ with ΔEL_t renders its regression coefficients insignificant but does not materially affect our results.

7 Conclusion

Using unique and granular datasets of European repo transactions and clearing houses (CCP), we analyse the effects of EMIR and Basel III regulation on short-term interest rates. First, we study the regulatory effects inducing clearing infrastructure to *supply* cash against safe collateral assets, as prescribed by EMIR law. Second, Basel III regulation discourages borrowing *demand* (collateral supply) through the leverage-constrainedness of repo dealers, particularly during specific reporting periods. In addition, we delve into the regulatory transmission mechanism by examining which assets and which banks are most affected.

Four main findings arise from our study: First, rather than being market-neutral, the collateralisation of CCPs' cash holdings mandated by EMIR exerts a significant downward pressure on short-term interest rates and thus supports the supply hypothesis. Second, the supply effect is stronger when the Basel III leverage ratio regulation is binding. This result is consistent with the idea that balance-sheet-constrained banks are less inclined to demand repos, which empirically supports the demand hypothesis. Third, new regulation widens repo rate dispersion affecting most repos with the largest convenience yield. Finally, banks that have been counterparties of CCPs lend more and borrow less (aggressively) in the interbank market, perhaps in the attempt of offsetting cash surplus and asset shortages.

Our analysis is relevant to policy makers as it highlights several unintended effects on short-term rates that are caused by some regulatory reforms. First, compliance with these regulations strengthens cash supply and collateral demand. This results in larger dispersion and downward pressure on interbank rates, which impedes monetary policy effectiveness (Duffie & Krishnamurthy, 2016).[37] This phenomenon has been attributed to various factors, including collateral scarcity due to central banks' extraordinary monetary policy instruments and market segmentation (Duffie et al., 2015). Our findings offer an alternative explanation and point to prudential regulations, which make CCPs new important market players and constrain the trading books and balance sheets of repo intermediaries.

Various remedies can be considered. First, regulators should consider the joint effects of existing and new regulations. For instance, more comprehensive inspection, as we propose in this paper, illuminates what the interaction between CCP compliance with EMIR rules and the Basel III leverage ratio regulation implies for short-term rates. Second, carefully (re-)designing some regulations might move us closer to the efficient frontier of market efficiency and financial stability (Duffie, 2018). For instance, the strong seasonalities around quarter ends can be mitigated by monitoring leverage ratios more frequently. In addition, the exemption of encumbered repo collateral assets from the leverage ratio rule would reduce the asymmetric treatment of repo and reverse repo and partially deter banks from window-dressing behaviour. Third, our results indicate that the negative effects on repo market functioning are due to constrained intermediaries. Rather than rolling back prudential regulations, other measures relaxing these constraints and promoting the de-intermediation of money markets should be contemplated. For instance, giving non-financials access to centrally cleared markets could free up space on dealers' balance sheets, and thereby mitigate these effects. Also, increasing netting efficiency, for example, by enhancing CCP-interoperability and compression services, could lead to a more efficient use of dealers' balance sheets.

[37]For instance, in recent years Euro repo rates have fallen below the lower bound of the ECB's interest rate corridor and have dispersed considerably, thus hindering the passthrough efficiency of the ECB's monetary policy.

Finally, the constraining effect of CCPs' reverse repo investments in dealers' balance sheets is bound to become more severe as central clearing is mandated for more and more financial products. To mitigate CCPs' increasing reverse repo investments, regulators could offer alternative ways of holding safe assets and grant CCPs full access to central bank deposit accounts.[38]

References

Acosta-Smith, J., Grill, M., & Lang, J. H. (2018). The leverage ratio, risk-taking and bank stability. *Bank of England Staff Working Paper, No. 766*. Retrieved from `https://www.bankofengland.co.uk/working-paper/2018/the-leverage-ratio-risk-taking-and-bank-stability` (Accessed: 7.3.2019)

Adrian, T., Boyarchenko, N., & Shachar, O. (2017). Dealer balance sheets and bond liquidity provision. *FRB of NY Staff Report, No. 803*.

Adrian, T., Etula, E., & Muir, T. (2014). Financial intermediaries and the cross-section of asset returns. *Journal of Finance*, *69*, 2557–2596.

Arora, N., Gandhi, P., & Longstaff, F. A. (2012). Counterparty credit risk and the credit default swap market. *Journal of Financial Economics*, *103*(2), 280–293.

Arrata, W., Nguyen, B., Rahmouni-Rousseau, I., & Vari, M. (in press). The scarcity effect of quantitative easing on repo rates: Evidence from the euro area. *Journal of Financial Economics*.

Bank for International Settlements. (2017). Repo market functioning. *CGFS Papers, No. 59*. Retrieved from `http://www.bis.org/publ/cgfs59.pdf` (Accessed: 24.10.2018)

Bank for International Settlements. (2018). *Annual economic report 2018.* Retrieved from `https://www.bis.org/publ/arpdf/ar2018e.htm` (Accessed: 14.3.2019)

Bank of England. (2015). *The Bank of England's Sterling Monetary Framework.* Retrieved from `https://www.bankofengland.co.uk/-/media/boe/files/markets/sterling-monetary-framework/red-book.pdf?la=en&hash=307B77F74A02B0A469CF44BD5DD7FF405849517F` (Accessed: 4.3.2019)

Bank of England. (2019). *Sterling monetary framework operating procedures.* Retrieved from `https://www.bankofengland.co.uk/-/media/boe/files/markets/sterling-monetary-framework/operating-procedures` (Accessed: 19.2.2019)

[38] Changing EMIR investment requirements would ultimately affect CCPs' risk profile. Hence, offering alternative investment options could also lead to alternative risks for CCPs and the wider market.

Bartolini, L., Hilton, S., Sundaresan, S., & Tonetti, C. (2011). Collateral values by asset class: Evidence from primary securities dealers. *Review of Financial Studies*, *24*, 248-278.

Bicu, A., Chen, L., & Elliot, D. (2017). The leverage ratio and liquidity in the GILT and repo markets. *Bank of England Staff Working Paper*, *No. 690*. Retrieved from `https://www.bankofengland.co.uk/working-paper/2017/the-leverage-ratio-and-liquidity-in-the-gilt-and-repo-markets` (Accessed: 7.3.2019)

Boissel, C., Derrien, F., Ors, E., & Thesmar, D. (2017). Systemic risk in clearing houses: Evidence from the European repo market. *Journal of Financial Economics*, *125*(3), 511–536.

Copeland, A., Martin, A., & Walker, M. (2014). Repo runs: Evidence from the tri-party repo market. *Journal of Finance*, *69*(6), 2343–80.

Corradin, S., & Maddaloni, A. (in press). The importance of being special: repo markets during the crisis. *Journal of Financial Economics*.

Cœuré, B. (2012). *Collateral scarcity – a gone or a going concern?* Retrieved from `https://www.ecb.europa.eu/press/key/date/2012/html/sp121001.en.html` (Accessed: 4.2.2019)

Cœuré, B. (2017). *The known unknowns of financial regulation* [Panel contribution at the conference on "Rethinking Macroeconomic Policy"]. Retrieved from `https://www.ecb.europa.eu/press/key/date/2017/html/ecb.sp171012_1.en.html` (Accessed: 4.2.2019)

Cœuré, B. (2019). *The case for cooperation: cross-border CCP supervision and the role of central banks.* Retrieved from `https://www.ecb.europa.eu/press/key/date/2019/html/ecb.sp190227~cf2acdb23d.en.html` (Accessed: 10.6.2019)

Domanski, D., Gambacorta, L., & Picillo, C. (2015). Central clearing: Trends and current issues. *BIS Quarterly Review*, *December 2015*, 59–76.

Du, W., Gadgil, S., Gordy, M. B., & Vega, C. (2016). *Counterparty risk and counterparty choice in the credit default swap market.* (Finance and Economics Discussion Series 2016-087)

Du, W., Tepper, A., & Verdelhan, A. (2018). Deviations from covered interest rate parity. *Journal of Finance*, *73*(3), 915–957.

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

Duffie, D. (2016). Financial regulatory reform after the crisis: An assessment. *ECB Forum on Central Banking*. Retrieved from `https://www.ecb.europa.eu/pub/conferences/ecbforum/shared/pdf/2016/duffie_paper.pdf` (Accessed: 26.10.2018)

Duffie, D. (2017). Financial regulatory reform after the crisis: An assessment. *Management Science*, *64*(10), 4835–4857.

Duffie, D. (2018). *Post-crisis bank regulations and financial market liquidity.* Bank of Italy: Thirteenth Paolo Buffi Lecture. Retrieved from `https://www.darrellduffie.com/uploads/policy/DuffieBaffiLecture2018.pdf` (Accessed: 31.12.2018)

Duffie, D., & Krishnamurthy, A. (2016). Passthrough efficiency in the fed's new monetary policy setting. *Kansas City Federal Reserve Symposium on Designing Resilient Monetary Policy Frameworks for the Future.* Retrieved from `https://www.gsb.stanford.edu/sites/gsb/files/publication-pdf/jh-september-8-2016-bw.pdf` (Accessed: 26.10.2018)

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

EuroCCP. (2018). *CPMI-IOSCO Quantitative Disclosure.* Retrieved from `https://euroccp.com/document/cpmi-iosco-quantitative-disclosure/` (Accessed: 2.3.2019)

European Central Bank. (2015). *Euro money market survey.* Retrieved from `https://www.ecb.europa.eu/pub/pdf/other/euromoneymarketsurvey201509.en.pdf` (Accessed: 24.10.2018)

European Commission. (2013). Commission Delegated Regulation (EU) No 153/2013. *Official Journal of the European Union*, *L52*, 41–74. Retrieved from `https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:052:0041:0074:EN:PDF` (Accessed: 28.10.2018)

Financial Stability Board. (2017a). *OTC derivatives market reforms: Twelfth progress report on implementation.* Retrieved from `http://www.fsb.org/2017/06/otc-derivatives-market-reforms-twelfth-progress-report-on-implementation/` (Accessed: 17.1.2019)

Financial Stability Board. (2017b). *Review of OTC derivatives market reforms: Effectiveness and broader effects of the reforms.* Retrieved from `http://www.fsb.org/2017/06/review-of-otc-derivatives-market-reform-effectiveness-and-broader-effects-of-the-reforms/` (Accessed: 17.1.2019)

Gorton, G. B. (2017). The History and Economics of Safe Assets. *Annual Review of Economics*, *9*, 547–586.

Gorton, G. B., & Metrick, A. (2012). Securitized banking and the run on repo. *Journal of Financial Economics*, *104*, 425–51.

Grill, M., Jakovicka, J., Lambert, C., Nicoloso, P., Steininger, L., & Wedow, M. (2017). Recent developments in euro area repo markets, regulatory reforms and their impact on repo market functioning. *Financial Stability Review*, *November 2017*, 158–171. Retrieved from `https://www.ecb.europa.eu/pub/fsr/shared/pdf/ecb.sfcfinancialstabilityreview201711.en.pdf` (Accessed: 28.10.2018)

Haldane, A. G. (2017). *Rethinking financial stability* [Speech given at the conference on "Rethinking Macroeconomic Policy"]. Retrieved from `https://www.bankofengland.co.uk/-/media/boe/files/speech/2017/rethinking-financial-stability` (Accessed: 4.2.2019)

He, Z., Kelly, B., & Manela, A. (2017). Intermediary asset pricing: New evidence from many asset classes. *Journal of Financial Economics*, *126*, 1–35.

He, Z., & Krishnamurthy, A. (2013). Intermediary asset pricing. *American Economic Review*, *103*, 732–770.

Kotidis, A., & van Horen, N. (2018). Repo market functioning: the role of capital regulation. *Bank of England Staff Working Paper*, *746*. Retrieved from `https://www.bankofengland.co.uk/-/media/boe/files/working-paper/2018/repo-market-functioning-the-role-of-capital-regulation.pdf` (Accessed: 28.10.2018)

Krishnamurthy, A., Nagel, S., & Orlov, D. (2014). Sizing up repo. *Journal of Finance*, *69*(6), 2381–417.

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

Loon, Y. C., & Zhong, Z. K. (2014). The impact of central clearing on counterparty risk, liquidity, and trading: Evidence from the credit default swap market. *Journal of Financial Economics*, *112*(1), 91-115.

Mancini, L., Ranaldo, A., & Wrampelmeyer, J. (2016). The euro repo interbank market. *Review of Financial Studies*, *29*, 1747-1779.

Modigliani, F., & Sutch, R. (1966). Innovations in interest rate policy. *American Economic Review*, *56*, 178–197.

Munyan, B. (2015). Regulatory arbitrage in repo markets. *Office of Financial Research*, *Working Paper No. 15-22*. Retrieved from `https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2685592` (Accessed: 24.10.2018)

Musto, D. K. (1997). Portfolio disclosures and year-end price shifts. *Journal of Finance*, *52*, 1563–1588.

Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica*, *49*, 1399–1416.

Nyborg, K. G. (2016). *Collateral Frameworks: The Open Secret of Central Banks*. Cambridge University Press.

Ogden, J. (1987). The end of month as a preferred habitat: a test of operational efficiency in the money market. *Journal of Financial and Quantitative Analysis*, *22*, 329–343.

Park, S., & Reinganum, M. (1986). The puzzling price behavior of treasury bills that mature at the turn of calendar months. *Journal of Financial Economics*, *16*, 267–283.

Pelizzon, L., Subrahmanyam, M. G., Tomio, D., & Uno, J. (2018). Central bank-driven mispricing. *SAFE Working Paper Series*, *No 226*.

Roll, R. (1984). A simple implicit measure of the effective bid-ask spread in an efficient market. *Journal of Finance*, *39*, 1127–1139.

Trebbi, F., & Xiao, K. (2017). Regulation and market liquidity. *Management Science*, *Articles in Advance*, 1–20. Retrieved from `https://doi.org/10.1287/mnsc.2017.2876` (Accessed: 7.3.2019)

Figure 1: European Repo Rates

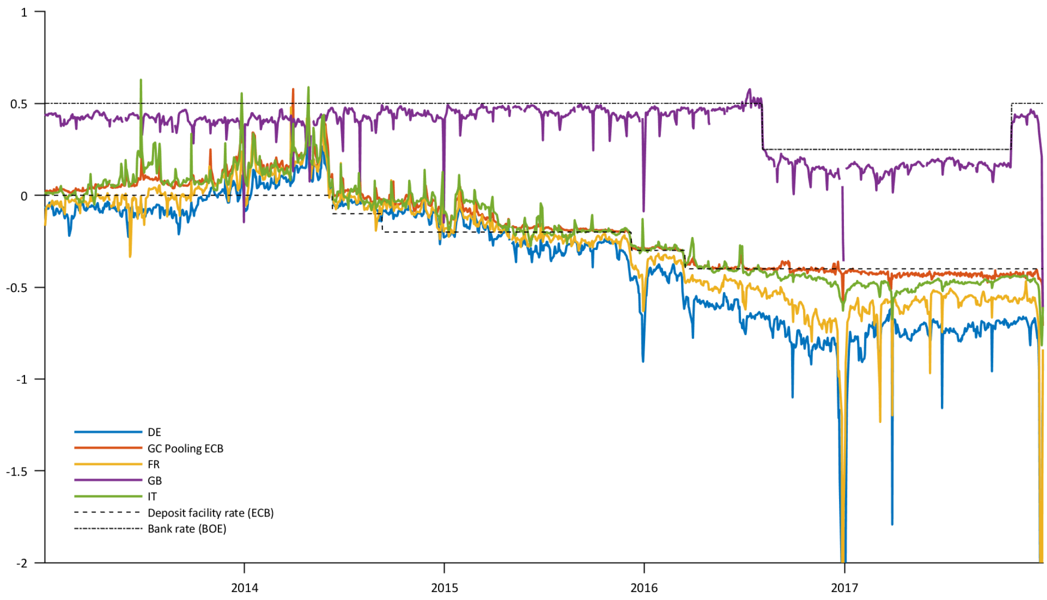


Figure 2: Impact of Repo Trading on the Leverage Ratio

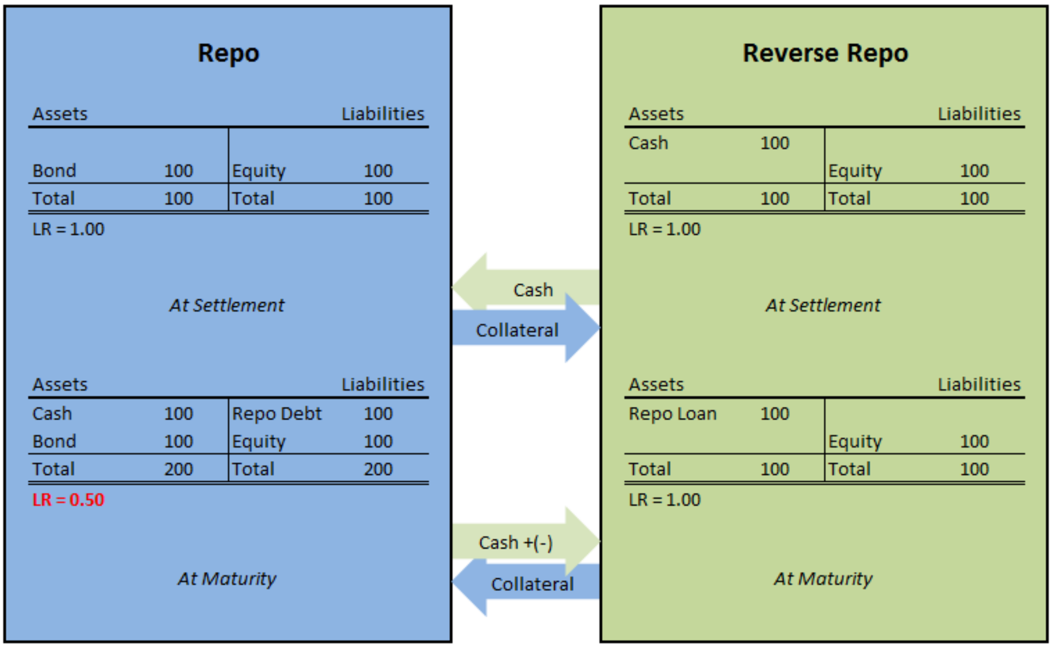
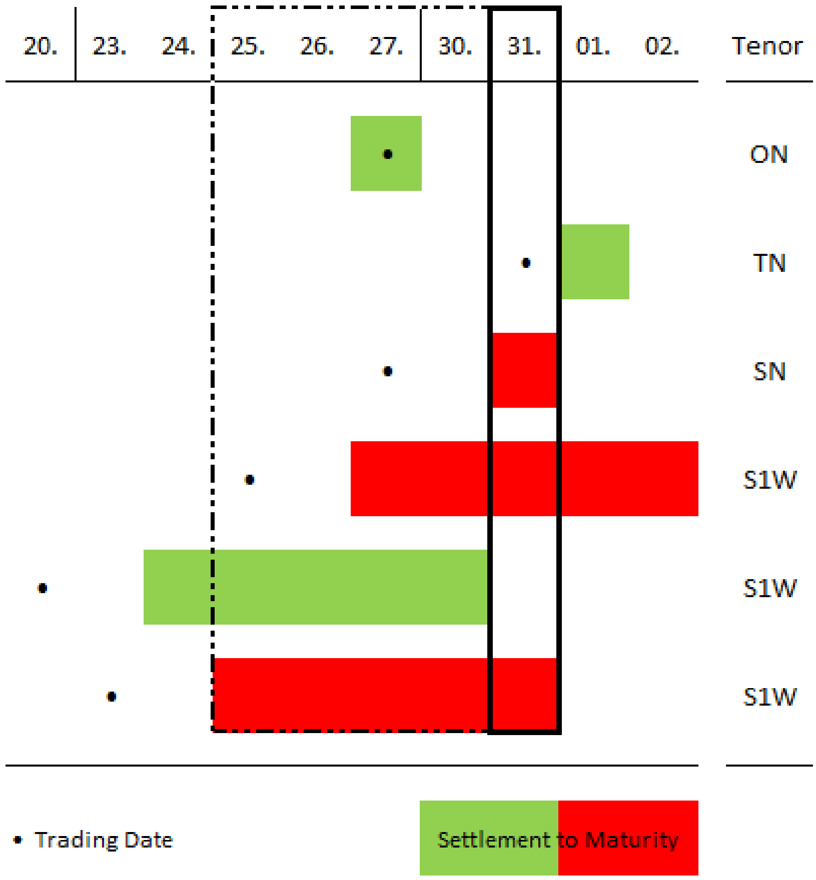


Figure 3: Balance Sheet Impact around Reporting Days



Each column corresponds to a business day, with the thick bordered column representing the leverage reporting day. Each row corresponds to a repo contract. The coloured bars highlight those days on which each repo ends up on the balance sheet. The red bars correspond to repos that show up on the balance sheet during the reporting day. All one-week repos settled during the four days before the reporting days end up on the balance sheet on the reporting days unlike the one-day repos. Note that the trading day is irrelevant. Hence, our t index always denotes settlement dates.

Table 1: Breakdown of the Repo Dataset

	Transactions (in mn)	Volume (in EUR tn)	Transactions (share in %)	Volume (share in %)
Total	13.24	326.3	100.0	100.0
BrokerTec	8.76	189.7	66.1	58.1
Eurex Repo	0.33	36.9	2.5	11.3
MTS	4.16	99.7	31.4	30.6
CCP	12.86	317.1	97.1	97.2
Bilateral	0.38	9.2	2.9	2.8
Euro	12.23	296.9	92.3	91.0
Sterling	1.01	29.4	7.7	9.0
DE	2.90	74.4	21.9	22.8
ES	1.14	21.2	8.6	6.5
FR	1.36	31.0	10.3	9.5
GB	1.01	29.4	7.7	9.0
IT	4.08	97.8	30.8	30.0
NL	0.64	12.3	4.9	3.8
Other	2.09	60.3	15.8	18.5
1-day	12.99	313.6	98.1	96.1
>1-day	0.25	12.7	1.9	3.9

Table 2: Supply Effect on Repo Rates

	$Rate_{i,t}$		
	(1)	(2)	(3)
$Reverse_{i,t}$	-4.525^{***}	-4.491^{***}	-1.509^{***}
	(1.297)	(1.283)	(0.576)
$Orderflow_{i,t}$	0.163^{**}	0.163^{**}	0.172^{***}
	(0.078)	(0.079)	(0.032)
$Bonds_{i,t}$		0.065	-0.219
		(0.801)	(0.300)
$CIP_{i,t}$			155.946^{***}
			(55.686)
$VSTOXX_{t-1}$			0.117^{***}
			(0.021)
$\Delta PSPP_{i,t}$			-27.919^{***}
			(5.487)
$Rate_{i,t-1}$	0.502^{***}	0.502^{***}	0.781^{***}
	(0.063)	(0.063)	(0.021)
Fixed Effects	Segment	Segment	Segment
Observations	13193	13193	12709
Segments	13	13	13
Adjusted R^2	0.490	0.490	0.689

$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Note: Robust standard errors clustered at the segment and quarter are reported.

Table 3: Demand Effects on Repo Rates

	$Rate_{i,t}$		
	(4)	(5)	(6)
$Reverse_{i,t}$	-3.297^{***}	-3.318^{***}	-0.813^{**}
	(1.127)	(1.129)	(0.364)
$Reverse_{i,t} \cdot 1W_i$	-13.464^{***}	-13.477^{***}	-7.874^{**}
	(4.908)	(4.878)	(3.092)
$Reverse_{i,t} \cdot BeforeEoQ_t$	0.512	0.511	0.035
	(0.835)	(0.835)	(0.508)
$Reverse_{i,t} \cdot BeforeEoQ_t \cdot 1W_i$	-27.933^{**}	-27.941^{**}	-27.767^{**}
	(13.515)	(13.516)	(13.399)
$BeforeEoQ_t$	-2.745	-2.746	-2.935^{*}
	(2.904)	(2.903)	(1.748)
$BeforeEoQ_t \cdot 1W_i$	-101.073^{**}	-101.097^{**}	-98.126^{**}
	(48.681)	(48.686)	(47.360)
$Orderflow_{i,t}$	0.173^{**}	0.172^{**}	0.174^{***}
	(0.080)	(0.080)	(0.032)
$Bonds_{i,t}$		-0.042	-0.297
		(0.810)	(0.318)
$CIP_{i,t}$			123.014^{***}
			(33.630)
$VSTOXX_{t-1}$			0.116^{***}
			(0.021)
$\Delta PSPP_{i,t}$			-32.537^{***}
			(5.198)
$Rate_{i,t-1}$	0.495^{***}	0.495^{***}	0.769^{***}
	(0.062)	(0.062)	(0.022)
Fixed Effects	Segment	Segment	Segment
Observations	13193	13193	12709
Segments	13	13	13
Adjusted R^2	0.508	0.507	0.700

$^{*}\,p < 0.10$, $^{**}\,p < 0.05$, $^{***}\,p < 0.01$

Note: Robust standard errors clustered at the segment and quarter are reported.

Table 4: Effects on Repo Rate Dispersion

	$Spread_{i,t}$				
	(7)	(8)	(9)	(10)	(11)
$BaseReverse_{i,t}$	7.269^{***} (0.587)				
$QuoteReverse_{i,t}$	0.377 (1.344)				
$TotalReverse_t$		4.832^{***} (0.393)	3.572^{***} (0.352)	5.122^{***} (0.342)	3.755^{***} (0.204)
$TotalReverse_t \cdot 1W_i$				-2.734^{***} (0.797)	-2.195^{***} (0.605)
$TotalReverse_t \cdot BeforeEoQ_t$				-2.141^{**} (1.012)	-1.956^{***} (0.722)
$TotalReverse_t \cdot BeforeEoQ_t \cdot 1W_i$				21.548^{***} (7.948)	21.369^{**} (8.296)
$BeforeEoQ_t$				4.299^{***} (0.878)	3.194^{***} (0.667)
$BeforeEoQ_t \cdot 1W_i$				3.957 (2.750)	3.833 (2.477)
$BaseOrderflow_{i,t}$	-0.089^{***} (0.024)	-0.062^{***} (0.022)	-0.084^{***} (0.019)	-0.061^{***} (0.022)	-0.080^{***} (0.018)
$QuoteOrderflow_{i,t}$	0.172^{***} (0.029)	0.146^{***} (0.027)	0.112^{***} (0.022)	0.147^{***} (0.026)	0.113^{***} (0.021)
$BaseBonds_{i,t}$	-2.170^{***} (0.313)	-0.375 (0.395)	-0.423 (0.292)	-0.515 (0.360)	-0.405 (0.290)
$QuoteBonds_{i,t}$	-0.056 (0.447)	-0.587 (0.381)	-0.027 (0.305)	-0.711^{*} (0.365)	-0.182 (0.287)
$CIP_{i,t}$			-101.500^{***} (38.106)		-47.210^{***} (13.880)
$VSTOXX_{t-1}$			-0.079^{***} (0.019)		-0.085^{***} (0.019)
$\Delta BasePSPP_{i,t}$			-0.320 (3.181)		4.316^{**} (2.185)
$\Delta QuotePSPP_{i,t}$			-8.142^{*} (4.683)		-7.431^{*} (4.324)
$Spread_{i,t-1}$	0.430^{***} (0.029)	0.407^{***} (0.027)	0.543^{***} (0.027)	0.401^{***} (0.027)	0.534^{***} (0.028)
Fixed Effects	Segment	Segment	Segment	Segment	Segment
Observations	14419	14419	13867	14419	13867
Segments	15	15	15	15	15
Adjusted R^2	0.394	0.412	0.441	0.434	0.460

$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Note: Robust standard errors clustered at the segment and quarter are reported.

Table 5: Effects on Banks' Individual Behavior

	$MarketBorrow_{i,t}$	$LimitBorrow_{i,t}$	$MarketLend_{i,t}$	$LimitLend_{i,t}$
	(12)	(13)	(14)	(15)
$Reverse_t$	0.00173 (0.00144)	0.00184 (0.00156)	-0.00391^{**} (0.00160)	0.00042 (0.00139)
$Reverse_t \cdot Counterparty_i$	-0.00191 (0.00167)	-0.00453^{**} (0.00186)	0.00688^{***} (0.00203)	-0.00024 (0.00175)
$Bonds_t$	-0.00189 (0.00139)	0.00042 (0.00154)	0.00090 (0.00170)	0.00032 (0.00140)
$OrderShare_t$	0.13873^{***} (0.00825)	-0.13573^{***} (0.00921)	-0.14850^{***} (0.00982)	0.16841^{***} (0.00886)
$\Delta Rate_t$	0.01722^{*} (0.00999)	-0.00356 (0.01281)	-0.00370 (0.01374)	-0.00668 (0.01178)
$log(Volume_t)$	-0.00810 (0.00968)	0.03252^{***} (0.01066)	-0.01238 (0.01169)	-0.01181 (0.01028)
$EffectiveSpread_t$	-0.00008 (0.00009)	-0.00002 (0.00009)	-0.00018^{*} (0.00010)	0.00022^{**} (0.00010)
CIP_t	0.23499^{**} (0.09831)	-0.14051 (0.10171)	-0.28874^{**} (0.12252)	0.16854 (0.11207)
$VSTOXX_{t-1}$	0.00013 (0.00024)	-0.00073^{***} (0.00025)	0.00033 (0.00028)	0.00023 (0.00026)
$MarketBorrow_{i,t-1}$	0.34452^{***} (0.00949)			
$LimitBorrow_{i,t-1}$		0.47039^{***} (0.00979)		
$MarketLend_{i,t-1}$			0.44613^{***} (0.00942)	
$LimitLend_{i,t-1}$				0.35444^{***} (0.00993)
Fixed Effects	Bank & Month	Bank & Month	Bank & Month	Bank & Month
Observations	69181	69181	69181	69181
Banks	118	118	118	118
Adjusted R^2	0.130	0.230	0.208	0.137

$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Note: Robust standard errors clustered at banks and months are reported.