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

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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.

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1 Introduction

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.

— Benoît Cœré (27 February 2019)

The well-functioning of the market for repurchase agreements (repo) is crucial for financial markets as it allows a wide range of financial actors to efficiently manage their inventory of cash and securities.

In response to the financial crisis of 2007-2009, G20 policy makers around the world launched an ambitious agenda to reform and strengthen the financial system. Central to the agenda were new prudential regulations. These included Basel III principles and the reform of over-the-counter (OTC) derivatives mandating the clearing of standardised derivative contracts by central counterparties (CCPs). How does the new regulatory framework affect short-term interest rates? And if it does, then why?

This paper addresses these important questions by analysing a comprehensive dataset of European repurchase agreements (repo) together with regulatory data from central clearing services.[1] We test whether G20 reforms decrease short-term rates by increasing lending (*supply channel*) and by reducing repo loan borrowing (*demand channel*). To identify the regulatory effects, we utilise the asymmetric impact of Basel III and of European market infrastructure regulation (EMIR) on the demand and supply for repo loans. On the one hand, the EMIR regulation caps CCPs' unsecured cash holdings

[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 cash.

from the collection of margin leading to arrangements that ensure collateralisation with highly liquid financial instruments. Notably, European CCPs obtain these financial instruments as collateral of short-term secured loans, i.e. by entering into reverse repos.[2] On the other hand, the Basel III leverage ratio imposes balance sheet constraints on banks for repo cash borrowing, yet not on repo cash lending. Basel III leverage ratio thus reduces cash borrowing demand only for repos. We find compelling evidence for both supply and demand channels through which new regulation affects short-term rates.

A better understanding of how new regulations affect short-term interest rates and clearing infrastructure is relevant for at least three reasons. First, short-term funding has changed profoundly since the financial crisis. Nowadays, secured loans in the form of repos have become the main source of funding liquidity and have largely replaced traditional unsecured loans on a global scale. Thus, the efficient allocation of funding liquidity for financial institutions depends on how the repo market operates in the post-crisis regulatory framework.

Second, many monetary policies are implemented through short-term rates. Rates dispersion indicates market segmentation and frictions, and thus reflects search costs, monitoring efforts and information asymmetry. These effects impede the pass-through efficiency of monetary policy transmission (Duffie & Krishnamurthy, 2016a). This issue applies not only to conventional and unconventional operations but also to policy normalisation tools such as the reverse repurchase agreement facility of the Federal Reserve in the United States or the ECB's securities lending programme. Regarding conventional and unconventional operations, many central banks, including the ECB, implement

[2] As explained in Section 2, EMIR also allows CCPs to deposit cash in central banks or purchase individual securities. However, the reverse repo represents the flexible and efficient tool to comply with the EMIR regulation.

their policies with repos, whose rates determine the first part of the interest-rate term spectrum. Hence, well-functioning repo markets are paramount for effective monetary policy.

Third, regulatory reforms to combat financial crises have changed market participants' behaviours and imposed a number of regulatory constraints on banks with unknown effects and interactions (e.g. Haldane, 2017; Cœuré, 2017). Whilst new prudential regulations strengthened the stability of financial systems, regulations such as Basel III's leverage ratio might have created unintended effects such as disincentivising repo intermediation (Duffie, 2016),[3] inducing collateral scarcity (Cœré, 2012) and window-dressing at the end of reporting periods (BIS, 2017, pp. 20–28).[4] Furthermore, the Dodd-Frank Act and EMIR implementation have made central clearing mandatory for interest rate swaps and credit default swaps, thus making CCPs large actors in financial markets. Understanding these issues is crucial for phasing-in and redesigning the regulatory framework to approach the efficient frontier of potential levels of market efficiency and financial stability (Duffie, 2018).

Our analysis focuses on the reverse repo activity of clearing houses. Being determined by regulation, such activity provides a direct tool to identify a fairly exogenous supply of cash (demand of collateral assets) and an indirect tool to highlight the demand for cash (supply of assets). On the supply side,

[3]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).

[4]For instance, 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."

we take advantage of the EMIR regulation. It states that at least 95% of any cash position that remains in a clearing house'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 forced to reinvest cash in a given set of highly safe and liquid assets available on the market. The most convenient and flexible way to operationalise the EMIR rule is the temporary purchase of assets with reverse repos. Therefore, we first ask whether the fairly exogenous supply of cash from clearing houses[6] decreases short-term rates.

In addition to the supply hypothesis, the interaction between EMIR and Basel III regulations allows us to test the demand effect on short-term rates. The main idea is to analyse whether the repo supply arising from EMIR regulation more strongly decreases short-term rates at times when Basel III leverage ratio bites banks' (repo) borrowing demand the most. We do this by exploiting three features of the leverage ratio. First, it implies a different regulatory treatment of repo and reverse repos in terms of leverage ratios: starting from no pre-existing positions, a repo expands balance sheet size whereas a reverse repo does not.[7] Hence, banks are less inclined to demand repos whereas repo supply remains essentially unaffected. Second, banks face tighter balance sheet constraints during quarterly reporting periods. The comparison of repo rates with different maturities when the leverage ratio

[5]See Articles 44-45 of EMIR (EC, 2013, p. 63). For further details, see section 2.2.

[6]Any market participant, not just CCPs, making these investments would lower short-term rates in the same way. However, only CCP investments are driven by regulatory compliance with EMIR and hence can be seen as exogenous to the repo market.

[7]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. On the reverse repo side, the balance sheet size of the lender remains unchanged because on the asset side, 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.

regulation is binding gives rise to a difference-in-differences setting in the spirit of Du, Tepper, and Verdelhan (2018). Repo contracts expiring before the quarter end represent the "control group" as they are not subject to the leverage ratio requirement. However, contracts expiring after the quarter end represent the "treated group" as they expand a bank's balance sheet and thus generate higher capital costs. Third, the leverage ratio is an unweighted risk measure, meaning that balance sheet size rather than asset quality matters.[8]

In the remaining part of our paper, we analyse supply and demand effects on repo spreads and volume (so-called order flows). We consider two definitions of repo spreads: First, the yield differential between a repo and reverse repo composing a collateral swap of two assets. From the perspective of the safe asset literature (Krishnamurthy & Vissing-Jorgensen, 2012), a repo is a safe asset (Gorton, 2017) and this spread represents a differential of "convenience yields" capturing safety and liquidity premia. If this spread involves two safe assets (e.g. French government bonds for German ones), then it can only be explained by the difference in the latter premium coming from liquidity and collateral services (e.g., fungibility and netting benefits of the two assets). From the trader's point of view, this spread suggests a deviation from a near-arbitrage condition, which should arise from some frictions such as collateral scarcity or market segmentation. Second, we analyse the yield spread between equivalent repos (i.e. same collateral and one-day maturities) but with different forward periods. According to the Expectations Hypothesis, forward rates should be unbiased predictors of spot rates and if existing at all, the spread should be constant. For instance, on average the yesterday's

[8]To rule out potential effects from other regulations, we analyse (collateral) assets that are affected equally by the Liquidity Coverage Ratio (LCR), by the Net Stable Funding Ratio (NSFR) and by Risk Weighted Assets (RWA). For instance, the studied assets belong to the Level 1 category of High Quality Liquid Assets (HQLA) and the repo term is shorter than the thirty-day LCR cut-off time.

tomorrow-next (TN) rate should forecast the today's overnight (ON) rate. A positive (negative) spread represents a forward discount (premium). We test whether supply effects enforced by the regulatory framework induce an increasing time-varying forward discount, which is embedded in short-term rates. Finally, we conduct a bank-level analysis to highlight whether banks borrowing cash from clearing houses in the over-the-counter segment lend (borrow) more (less) in the interbank repo market. These patterns would be consistent with portfolio imbalance effects, that is, counterparty banks of clearing houses that are in excess of cash and short of assets tend to offset these positions in the interbank market.

We conduct our analysis based on two unique and very granular datasets. The first dataset includes all Euro and Sterling repos traded in the three main interbank platforms (BrokerTec, Eurex Repo, and MTS Repo) covering more than 70% of the total European repo market with a daily transaction volume of Euro 300 bn. The second dataset contains the reverse repo and bond investments of all clearing houses with reporting obligations to the Bank of England from November 2013 to December 2017.

We perform a series of panel regressions to uncover the main determinants of interbank repo rates. Our baseline model regresses volume-weighted daily interbank rates on aggregate clearing houses' reverse repos. We control for (i) interbank order flow (i.e., borrower-initiated minus lender-initiated repos), (ii) risk variables (e.g., VIX) accounting for possible margin procyclicality, (iii) the covered interest rate parity (CIP) "basis" capturing the connection between interest rates and FX rates, (iv) past repo rates, in order to control for persistent patterns in interest rates, (v) CCP purchases in the cash bond market, which can induce indirect effects on short-term rates such as "specialness," and (vi) fixed-effects for the country of the collateral asset.

If the supply hypothesis holds, we should find a significant negative coefficient on CCPs' reverse repo investments. Using a similar panel regression, we also analyse whether regulatory-driven repo supply increases repo spreads and lending volumes. It should be noted that our regression design captures cross-market effects as clearing houses conduct their reverse repos in the OTC segment. We analyse their impact in the interbank segment, which represents the lion's share of the entire European repo market. Next, we refine the panel regression model with a difference-in-differences analysis of repo rates "leaving" and "remaining" in banks' balance sheets during end-of-quarter reporting days. An additional significant decrease in the rates of the "remaining" repos would support the demand hypothesis. Finally, we perform bank-level panel regressions to analyse whether banks borrowing cash (selling assets) from (to) clearing houses lend more and borrow less in the interbank repo market.

Three main results emerge from our study. First, to conform to new regulation, clearing houses' lending exerts a pervasive and systematic downward pressure on short-term rates. In fact, CCPs' reverse repos to purchase EMIR-eligible assets significantly decrease short-term interest rates, thus supporting the supply hypothesis. Second, this effect increases during quarterly reporting dates, that is, when the Basel III leverage ratio imposes balance sheet constraints on banks demanding (but not lending) repos. This evidence suggests that the joint regulatory effects of EMIR and Basel III further decrease short-term rates, thus supporting the demand hypotheses. Third, we find that regulatory-driven supply has significant adverse effects on price dispersion and lending volume. In fact, supply induced by regulation increases (i) the net supply of repos in the interbank market, especially through counterparty banks of clearing houses that lend (borrow) more (leass) aggressively, (ii) the cross-sectional dispersion of short-term rates with strongest effects on the safest assets, and (iii) the time-varying forward discount. Overall, our results suggest that new regulation contributes to intermediaries' constrainedness, collateral (asset) scarcity, and convenience premium of safe assets.

We contribute to at least three strands of the literature. First, we provide empirical support for 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 affect how financial intermediaries trade and how they price short-term rates.[9] We also find that regulations determining portfolio positions of special institutions (i.e., clearing houses) affect dealers' capital and thus create heterogeneity in short-term rates. Our work comes closest to Du et al. (2018), who find that CIP deviations increase towards quarter-ends presumably due to banks facing tighter balance sheet constraints. Our contribution extends beyond their analysis by sharpening the strategy for identifying the supply and demand sources of intermediaries' constrainedness. We do this by studying the interaction between regulations affecting banks and clearing houses for the first time in the literature.

Second, we contribute to the literature on repos, which represent an important category of safe assets (Gorton, 2017).[10] Only few papers analyse the regulatory effects on repo rates. 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. Our study is the first to

[9] 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).

[10] 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).

highlight how the new mandatory framework forces clearing houses to reinvest their liquidity, which in turn reduces short-term interest rates. We also find that the additional supply stemming from new regulation creates spillover effects across segments of the repo market (i.e., from the OTC to the interbank segment), repo contracts (with different collateral assets), and maturities. The latter causes forward discounts and term structure effects in short-term rates. Our work is also relevant to the empirical analysis of the Expectations Hypothesis (EH) using short-term rates pioneered by Longstaff (2000b). Here, we provide evidence of a time-varying forward discount as a plausible explanation for the EH failure reported in Della Corte, Sarno, and Thornton (2008).

Third, we contribute to the nascent literature on central clearing. The empirical literature is mostly devoted to pricing effects of the post-crisis regulation mandating CCP on CDS.[11] We add to this literature by investigating regulatory effects on the well-functioning of the repo market and on clearing houses on their own, which have hitherto been considered market-neutral. In addition, 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). Rather than providing overall evidence of window-dressing effects, we present direct evidence of specific agents, clearing houses in our case, which regulation forces to invest in given assets and maturities. We also establish how their "preferred [regulatory] habitats" affect prices.

Section 2 introduces the regulatory reforms. Section 3 presents our datasets. Section 4 formalises our methodology and presents our results on the supply hypothesis. Section 5 examines the demand hypothesis while section 6 pro-

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

vides additional analyses. Section 8 provides various robustness tests. In conclusion, section 9 offers a short summary and policy advice.

2 Regulatory Context

We consider two sets of regulations. First, Basel III leverage ratio imposes balance sheet restrictions on banks and thus affects borrowing in the repo market (demand channel). Second, because of EMIR regulation European CCPs are under significant pressure to enter into secured loans such as reverse repos (supply channel). Below we describe those parts of these regulations that are relevant to our study and observe their interaction with repo markets.

2.1 Basel III

The Basel III framework, announced in 2010, was developed by the Basel Committee on Banking Supervision (BCBS). It aimed to strengthen the regulatory framework for banks covered areas from capital adequacy to liquidity and resolution. Capital requirements are central to Basel III. In particular the leverage ratio, defined as the ratio of Tier 1 capital divided by all on- and off-balance sheet exposures, is a non-risk weighted capital ratio. It is designed to limit the build-up of leverage in a bank's 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, that is, using daily or month-end on-balance exposure amounts. Particularly in the UK, from January 2016 onwards, the regulator introduced a quarterly reporting for the seven larger UK banks based on 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 (from end-of-month) averaging.[12]

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

Regarding the repo market, calculation of the leverage ratio is asymmetric in Europe (see figure 1).

On the one hand, repo borrowers retain 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, and thus reduces the leverage ratio. On the other hand, no reverse repo enters the leverage ratio calculation because its buyer is not exposed to the risk of the collateral (except in the case of a default). Consequently, the collateral is not added as an asset in the bank's balance sheet. Further, the cash received is removed from the asset side and replaced by a repo loan receivable.

Hence, banks' intermediation in the repo market is constrained by the leverage ratio (see Domanski, Gambacorta, and Picillo (2015) and Duffie (2016)). This applies in particular to global systemically important banks

[12]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.

(G-SIB), which 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)). We later test whether these regulatory effects lead to a sharp drop in repo rates.[13]

2.2 European Market Infrastructure Regulation

EMIR legislation concerns the regulation of over-the-counter derivatives, central counterparties, and trade repositories. It establishes common rules for CCPs and trade repositories, and includes reporting requirements and risk management standards.

Of particular interest are Article 47 of EMIR and Commission Delegated Regulation (EU) No 153/2013 (EC, 2013, p. 63, Article 45). Both provide CCPs with guidance on investment policy.[14] 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 convert the cash collected via margin calls into reverse repos, government bonds, and when available, central bank deposits.

The size of CCP investments is likely to be considerable given the sheer size of the markets they clear and the high proportion of central clearing. This is perhaps a result of introducing mandatory clearing in EU in June 2016. At the end of 2016, 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

[13]Given the asymmetry of effects in the repo market, we expect a drop in borrowing (buying repos) but unaffected lending (buying reverse repos).

[14]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 [...].”

derivatives (e.g., FSB, 2017a, 2017b). Looking ahead, as the central clearing mandate is phased-in, the size of the CCP segment, and hence the size of CCP investments, is expected to grow even further.

This paper focuses on CCP investments in reverse repos. We consider these investments exogenous to the repo market for at least two reasons. First, the cash collected by CCPs does not reflect their own trading or intermediation, but instead the activities of their clearing members, which give rise to margin calls. Hence, the amount of cash held by CCPs, and consequently the size of CCP investment portfolios, is mechanically and exogenously determined by the trading of clearing members.

Second, CCP investments in the repo market are driven by the need for regulatory compliance with EMIR. While substituting reverse repos with other secured contracts (e.g., government bonds) is an option, this implies the purchase of individual securities (specific ISIN). This, in turn, translates into more expensive trades in less liquid markets than obtaining them as general collateral (GC) from a reverse repo. Moreover, EMIR (EC, 2013, p. 74) requires that the average time-to-maturity of CCP investment portfolios does not exceed two years. Nonetheless, our regression analysis adds CCP bond investments as a control variable, in order to err on the side of caution.

Alternatively, a CCP could deposit cash at central banks. This option is also limited because CCPs often do not have access to a central bank deposit account. Even if they do, deposit account usage is often restricted. For example, 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). However, we test our hypotheses during a sample period in which monetary policy transmission was not conventional and relied on asset purchase schemes or on quantitative easing. The onset of quantitative easing in 2009 suspended the reserves averaging scheme, except for CCPs. At least two days before a maintenance period commences, each CCP and the Bank of England must agree on a target level of reserves. The CCP must hold daily average reserves between 99% and 101% of said target. It must also pay a charge of 200 basepoints on the shortfall or excess (Bank of England, 2019, p. 7). CCPs are therefore more restricted than commercial banks in using their deposit accounts due to quantitative easing.[15]

On balance, the reverse repo represents a flexible and efficient way of clearing infrastructure to operationalise the EMIR regulation. Indeed, the data from CCPs' CPMI-IOSCO quantitative disclosures suggest that using reverse repos for cash investments is common practice among European CCPs.[16]

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).

[15]We would therefore expect commercial banks to exert a similar effect on repo supply and by extension on rates if the reserves averaging scheme were reactivated.

[16]For example, EuroCCP (2018) reports that 100% of cash received from clearing members is deposited with commercial banks over reverse repos. Similarly, Eurex Clearing (2018) states that "Eurex Clearing invests participants' cash on a secured basis via reverse repo to the extent possible. Uninvested cash is placed with the central bank of issue or, in currencies without central bank access, with highly rated commercial banks." However, they also report that more than 99% of cash received from clearing members is deposited with central banks, thus highlighting differences across CCPs.

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. Among others, every transaction involves the following factors: 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; and whether the repo is cleared by a CCP. We removed by hand some very few observations with obviously faulty rates.

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.

The breakdown reveals that the vast majority of repos are CCP-cleared with a maturity of one day. 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 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[17] (ON, TN, SN, S1W). 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) borrowing and lending volumes. We are unable to measure liquidity provision using (non-aggressive) limit orders, as our dataset contains no order book.

Figure 2 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, 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.

[17]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)).

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. The second pattern indicating wider cross-sectional dispersion of repo rates is a primary indicator of passthrough inefficiency of monetary policies (Duffie & Krishnamurthy, 2016b, 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.

3.2 Central Clearing Infrastructure

Our analysis uses daily investments from EMIR-regulated clearing infrastructures between November 2013 and December 2017. Although our quantities are representative of the entire central clearing infrastructure, confidentiality reasons prevent us from disclosing the clearing houses in our analysis. Nor are we able to divulge whether their investment activites 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 2.2). 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 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.

3.3 Other Data

In addition to repo market and clearing infrastructure data, we use commonly available foreign exchange and volatility measures. More specifically, we add the *covered interest rate parity basis* (CIP) and the *CBOE volatility index* (VIX) 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.[18] 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 foreign exchange 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, exchange 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 CBOE volatility index (VIX_t), downloaded from the CBOE website.[19] Being an important determinant of how much margin must be deposited at CCPs for a given trade, volatility can influence

[18] https://fred.stlouisfed.org/

[19] https://www.cboe.com/products/vix-index-volatility/vix-options-and-futures/vix-index/vix-historical-data

how much cash CCPs must invest in reverse repos and government bonds. As margin requirements are recalculated infrequently or are pre-established, we control for this variable with a lag of one day.

3.4 Descriptive Statistics

Descriptive statistics for the main variables are reported in table 2 below. For panel variables with a subscript i, we report the average statistic over the panel cross-section. As discussed in section 3.2, we standardise clearing infrastructure variables by the mean and by the standard deviation of total investments across the panel cross-section. Hence, the means and standard deviations of these variables are not informative and are not reported.

As we use these time-series variables in panel regressions, two issues are particularly relevant: stationarity and persistence. As non-stationarity may cause spurious estimates, we test the null-hypothesis of unit-roots in our data using the Levin-Lin-Chu (LLC) test for panel data, and the Augmented-Dickey-Fuller (ADF) test for univariate data.

We find that stationarity is validated for order flows and CIP bases by rejecting this null hypothesis. The LLC test cannot reject the unit-root for repo rates and the clearing houses' investment volumes.[20] Similarly, the ADF test cannot reject a unit-root in the VIX time series. Hence, it is paramount to show that our results are not driven by possible non-stationarities in our data. To that end, we supplement our analysis with appropriate robustness checks in section 8.[21]

Concerning repo rates, there are important theoretical considerations against

[20]Other panel unit-root tests (e.g., Harris-Tzavalis, Breitung and Im-Pesaran-Shin) reject the unit-root at the 5% significance level.

[21]Alternatively one could work in first differences. We do not take first differences because we would lose too much information contained in the clearing houses' investment volumes to retain significant results.

assuming a unit-root. Repo rates are not ordinary asset prices discovered in an efficient financial market where competitive trading ceaselessly impounds new information on prices, which theoretically entails a unit-root (Fama, 1995, p. 76). Rather than asset prices, repo rates are interest rates or returns on assets, which correspond to first differences of asset prices. Additionally, repo rates are very closely related to, and even targeted by, central banks' policy rates. Large deviations of repo from policy rates imply an arbitrage opportunity which, if exploited, will revert repo rates back to the policy rate. Therefore it is possible that the non-stationarity of repo rates indicated by the LLC test is a result of a trend in policy rates. Indeed, if we allow for a time trend in the LLC test, then the unit-root in repo rates is rejected at the 1% significance level. Similarly, if we work with spreads between repo and policy rates, the unit-root is rejected as the 1% significance level. Therefore, we conclude that repo rates follow a stationary process around policy rates (i.e. the deposit rate of the ECB and the bank rate of the Bank of England). We assume repo rates to be stationary, as is standard in the fixed income literature (e.g., Bierens, 1997; Wu & Zhang, 1996), but verify in a robustness check that our results are not influenced by possible non-stationarities stemming from policy rate changes.

Inspecting the reverse repo investments more closely by running an ADF test on each individual country, we find that all but one country's reverse repo investments are stationary. Excluding this country, the LLC test rejects the unit-root at the 1% level. We also find that bond investments, as well as the VIX index, approach non-stationarity. For this reason, we perform a robustness check by removing this particular country from the panel cross-section, and the bond investments and VIX control variables from our regression to establish that our results are not driven by these potential non-stationarities.

Furthermore, we find that these variables exhibit some degree of persistence, as can be seen from the AR(1) coefficients. We therefore add the first lag of the dependent variable as a control in all our regressions. Including lagged values of the dependent variable might introduce Nickell's (1981) bias into our regressions. However, this bias concerns 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. Our data features a long time-series of 1065 business days, but only 21 cross-sectional segments. Therefore, ordinary least-squares fixed-effects panel regressions are consistent in our case.

4 Supply Effects

The previous section (esp. figure 2) documents unusual patterns of short term rates. The extant literature offers some arguments to explain why a lender may accept an interest rate lower than the central bank's deposit rate. For instance, repos can become "special" due to collateral demand (Duffie, 1996). However, the patterns in figure 2 are systematic, pervasive and persistent, thus pointing to some major "frictions." The "ECB" line corresponds to a very large and liquid basket of collateral, which encompasses all assets eligible in the ECB's open market operations. A distinct feature of such *general collateral* repos (as opposed to *specific* repos) is that borrowers are free to deliver any of the assets listed in the basket as collateral. Hence, lenders do not know in advance which asset they will receive, which complicates reconciling this phenomenon with "specialness." The safe asset literature accounts for cross-sectional variations of repo rates by looking at asset characteristics such as safeness, liquidity, and collateral services. The "convenience yield" is the price spread between (nearly) safe assets that captures safety and liquidity premia increasing with supply scarcity (Krishnamurthy & Vissing-Jorgensen, 2012) and opportunity costs (Nagel, 2016).

In line with the safe asset literature, we test the hypothesis that regulations affect the supply of safe assets. By forcing clearing houses to buy and hold safe assets, the new regulatory architecture reduces the supply of safe assets, thus making them scarcer and increasing lending repo supply. Thus, we first test whether the regulatory-driven supply of repos by clearing houses decreases short-term rates. Next, we explain the method used to conduct this analysis.

Methods

We use a standard panel regression setup in our analysis. Equation (1) outlines the baseline regression equation used and adapted in subsequent sections.

$$Y_{i,t} = FE(i) + \lambda \cdot Reverse_{i,t} + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \epsilon_{i,t} \tag{1}$$

The i index denotes the cross-section of the panel, while $FE(i)$ denotes the standard fixed-effects dummies, one for every i. For the response variable $Y_{i,t}$, we first use interbank repo rates and later spreads between the repo rates of different countries or tenors, as well as different trading volumes and order flow measures.

The $Reverse_{i,t}$ variable contains the aggregate and standardised CCP reverse repo investment volume. The coefficient λ is our main variable of interest, as it captures the impact of CCP reverse repo investments in the OTC market on the interbank repo market variables given by $Y_{i,t}$. It is worth noting that $Reverse_{i,t}$ can be interpreted as the order flow (although standardised and with a negative sign) stemming from the CCPs in the OTC market. Hence, when using rates for $Y_{i,t}$ we occasionally refer to λ as the *price impact* of the CCP reverse repo investments. We do so, although the CCPs trade OTC and the interbank repo rates are traded in an electronic market with a central limit order book. Thus, it is important to remember that λ captures a spillover effect. This is transmitted into the interbank market through CCPs' OTC counterparties, which in many cases are at the same time repo dealers in the interbank market. Indeed, by replacing $Y_{i,t}$ with interbank order flows (in section 6.3), we show that parts of CCP order flow appear in interbank order flow in a manner consistent with the constrained leverage of repo dealers.

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

$$\boldsymbol{X}_{i,t} = \begin{bmatrix} Y_{i,t-1} \\ Orderflow_{i,t} \\ Bonds_{i,t} \\ CIP_{i,t} \\ VIX_{t-1} \end{bmatrix}$$

First, we add the first lag of the response variable as these quantities exhibit some degree of persistence, even though stationary is warranted according to the unit-root tests in section 3.4.[22]

Second, to account for endogenous demand and supply within the interbank market, we add interbank order flow as a control. When repo rates are regressed on it, the estimated coefficient captures the order flow price impact within the interbank repo market.

Third, we add CCPs' aggregate and standardised outright government bonds purchases as a control, because large purchase-volumes of bonds can

[22]In other settings, the price impact is estimated based on the first differences of a non-stationary price time series. However, as our prices (i.e. repo rates) are stationary, we work in levels to avoid losing valuable information by differencing. Nevertheless, we compromise and nest the original price impact regression within our specification by adding lagged values, which does not qualitatively change our results.

indirectly lower repo rates through the cash bond market, that is, collateral becomes scarce (Duffie, 1996). Hence, if $Reverse_{i,t}$ and $Bonds_{i,t}$ are correlated, ommiting $Bonds_{i,t}$ from the regression would lead to an omitted variable bias in the coefficient λ.

Finally, 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).

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 weaken our diff-in-diff identification strategy (see section 5) because all repo tenors under scrutiny are equally affected during these days.

To analyse supply effects due to EMIR on repo rates, we replace $Y_{i,t}$ in regression (1) with the interbank volume-weighted average repo rate $Rate_{i,t}$. We abbreviate the sum of fixed-effects, control variables and the error term of (1) as "…". Our first regression (a) is thus given by

$$Rate_{i,t} = \lambda \cdot Reverse_{i,t} + \dots \tag{a}$$

This estimates the price impact λ of CCP reverse repo investments. Consistent with the supply hypothesis, λ should be significantly negative as increasing supply while holding demand constant should lower prices (i.e., rates in our case) in a non-fully-elastic environment.

Results

Regression (a) in table 3 estimates the price impact of CCP reverse repo investments. Overall, the observed significant negative coefficient supports our supply hypothesis. Further, every standard deviation increase in reverse repo investments lowers interbank repo rates by 1.559 basepoints. All estimated coefficients of the control variables exhibit the expected signs and are significant (except from the bonds purchase variable, whose a p-value is slightly above 5%). These results are consistent with the idea that CCP reverse repo investments due to new regulation contribute to repo supply, and that the demand curve is downward-sloping. It also highlights that the EMIR rule, which leads clearing infrastructures to invest in safe assets, contributes to safe asset scarcity rather than being market neutral. This partly explains why repo rates have recently fallen below central bank deposit rates.

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 analysis to identify the demand effect stemming from the Basel III leverage ratio.

The repo accounting practices outlined in section 2.1 highlight that leverage ratio pressures have an asymmetric impact on repo traders. More specifically, 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. Cutting back repo positions hence increases a bank's leverage ratio 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.

In principle, the shape of the repo demand curve can be investigated by exploiting normal variation in repo supply. To this end, high-quality exogenous variation in repo supply is needed. CCPs' reverse repo investment volume can serve this purpose (see section 2.2). 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 price impact of reverse repos becomes more severe with falling repo demand. This identification strategy implicitly assumes that repo supply follows 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 price impact of CCPs' reverse repo investments becomes stronger (i.e., the λ in (1)). We employ a difference-in-differences design to causally attribute these changes to leverage ratio regulation. An alternative approach would be to exploit differences in jurisdiction and policy implementation time, in order to separate "treated" repo traders affected by leverage ratio regulation from "untreated" repo traders. However, this approach has several disadvantages.

First, it is rather difficult to unambiguously assign the repo traders in our dataset to different jurisdictions, as most of them are internationally active. Furthermore, severe differences between European countries' implementation vanished with the EU-wide European Leverage Ratio Delegated Act, effective January 2015. It is hence likely that international banks adhere to very similar leverage regulation.

Second, many small differences (e.g., time of policy change, disclosure requirements, etc.) exist between countries (see BIS, 2018b, for an overview), many of which are poorly documented. It is hence difficult to assign banks to somewhat homogenous treated and non-treated groups.

Third, most banks satisfied leverage ratio requirements before the respective regulation became effective (Bucalossi & Scalia, 2016, p. 13), at least during disclosure days at quarter- or semester-end. Relying on the exact policy implementation date is therefore not worthwhile. It is much more plausible that the effect of leverage ratio regulation emerged gradually while banks were preparing for regulation to become effective.

Finally, even if we were able to form convincing treated and non-treated groups, the repo transactions in our dataset are traded within an anonymous central limit order book. We would therefore not expect treated banks to negotiate significantly different rates than non-treated banks. Hence, our identification strategy would not work for repo rates.

We therefore assign different repo contracts rather than repo traders to treated and non-treated groups. 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 frequency. 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 tend to increase sharply 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, because it matures before that date. However, a one-month forward position traded on the same day will end up on the balance sheet on 31 March, and is hence affected by leverage ratio regulation. Therefore, CIP violations show up for one week (one month) before the end of the quarter for one-week (one-month) forwards.

Analysing heavily traded one-day and one-week tenors enables us to exploit the same differences in the repo market (see figure 9). 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. We claim that a change in this difference must be caused by falling borrowing demand due to leverage ratio regulation.

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

$Reverse_{i,t}$.

$$\begin{aligned} Y_{i,t} = FE(i) + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \eta \cdot BeforeEoQ_t \\ + \lambda_1 \cdot Reverse_{i,t} + \lambda_2 \cdot 1W_i \cdot Reverse_{i,t} + \lambda_3 \cdot BeforeEoQ_t \cdot Reverse_{i,t} \\ + \lambda_4 \cdot \ 1W_i \cdot BeforeEoQ_t \cdot Reverse_{i,t} + \epsilon_{i,t} \end{aligned} \tag{2}$$

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. This is our main variable of interest to test the demand hypothesis. We also add the uninteracted $BeforeEoQ_t$ term to account for overall differences in the level of $Y_{i,t}$ 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 $FE(i)$.

We estimate the difference-in-differences estimator (2) using rates as the dependent variable to analyse the impact of leverage ratio regulation on repo demand and short-term interest rates.

$$\begin{aligned} Rate_{i,t} = \lambda_1 \cdot Reverse_{i,t} + \lambda_2 \cdot 1W_i \cdot Reverse_{i,t} + \lambda_3 \cdot BeforeEoQ_t \cdot Reverse_{i,t} \\ + \lambda_4 \cdot 1W_i \cdot BeforeEoQ_t \cdot Reverse_{i,t} + \eta \cdot BeforeEoQ_t + \ldots \end{aligned} \tag{b}$$

Here, λ_4 is the main variable of interest, as it captures an additional price impact on repos, which end up on the balance sheet during leverage-ratio reporting days. Leverage-constrained dealers are more reluctant to enter into repo contracts that extend their balance sheets. If $Reverse_{i,t}$ increases, more of these dealers' limited balance sheet space is used to satisfy CCPs' reverse repo orders and less balance sheet space is 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 4 shows the estimates from the difference-in-differences regression (b), 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 severely. While the former experience a non-significant additional price impact of -0.039 bp per standard deviation, the latter suffer from an additional staggering price impact of -26.383 bp per standard deviation (with a P-value of 5.2%). Assuming that repo supply does not change due to leverage ratio concerns (as discussed above), a stronger price impact must be caused by decreasing repo demand. More specifically, the slope of the demand curve must become more negative. Our results suggest that repo demand falls sharply for those repos (one-week) that end up on the balance sheet during the end-of-quarter and hence worsen a bank's leverage ratio. In contrast, the other repos (one-day) are not affected because they mature before the end-of-quarter.

6 Additional Tests

Having investigated the impact of EMIR and Basel III regulations on the short-term interest rate level, we now extend our analysis by addressing three questions: whether regulation induces rate dispersion, affects forward discounts and impacts interbank order flows.

6.1 Rate Dispersion

Methods

Regarding rate dispersion, we investigate whether CCP reverse repo investments drive a wedge between two countries' interbank repo rates. 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.

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

We exclude Sterling repos from these regressions to ensure that we only take spreads between Euro repos. To ensure the positivity of $Spread_{i,t}$, we fix the base b to the country historically exhibiting the lowest repo rates. Thus, every i corresponds to one (q, m)-combination.

Substituting the rates regression equation (a) with this spread, as well as rearranging and simplifying terms, produces our first dispersion panel regression equation.

$$Spread_{i,t} = FE(i) + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \lambda_q \cdot \overbrace{Reverse_{q,t}}^{QuoteReverse_{i,t}} + \lambda_b \cdot \overbrace{Reverse_{b,t}}^{BaseReverse_{i,t}} + \epsilon_{i,t} \tag{c}$$
$$= \lambda_q \cdot QuoteReverse_{i,t} + \lambda_b \cdot BaseReverse_{i,t} + \dots$$

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

$$\boldsymbol{X}_{i,t} = \begin{bmatrix} Spread_{i,t-1} \\ QuoteOrderflow_{i,t} \\ BaseOrderflow_{i,t} \\ QuoteBonds_{i,t} \\ BaseBonds_{i,t} \\ CIP_{EUR,t} \\ VIX_{t-1} \end{bmatrix}$$

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

However, this does not account for potential spillover effects between countries. For example, if CCP reverse repo investments into the base country also depress the quote countries' repo rates, the sign of λ_b is not determined. Such a spillover effect is plausible as the leverage ratio is an unweighted risk-measure and hence does not differentiate between repos with different collateral. Repo dealers cutting back some type of repo positions because their leverage ratio is too low do so regardless of whether their balance sheet space is already occupied by the same or by other types of repo positions. Hence, the sign of these coefficients depends on whether the price impacts identified in the rates panel regressions are contained within the collateral country or spill over onto the rest of the market.

Furthermore, a positive spread lends itself to two meaningful interpretations: First, it can regarded as a "convenience yield" between two assets (Krishnamurthy & Vissing-Jorgensen, 2012). If both are safe, the spread ought to capture some additional liquidity or collateral services (e.g., fungibility and netting benefits) provided by the asset traded at the lower yield (higher price). Second, the spread can be seen as a near-arbitrage opportunity. This is the case because both repos are traded electronically in an anonymous order book and are centrally cleared, thus minimising the risk differences. One plausible reason why dealers do not exploit these opportunities is that this requires balance sheet space and hence creates regulatory costs (Duffie, 2016). As a result, dealers' the balance-sheet-constrainedness may introduce wedges between otherwise very similar instruments (Du et al., 2018, pp. 952–953). We argue above that CCP reverse repo investments constrain dealers balance sheets due to leverage ratio regulation. If this is the case, it is plausible that any reverse repo investments increase spreads regardless of the collateral country.

The joint effect of the given estimates λ_b and λ_q is difficult to assess, as this depends on relative coefficient sizes and on reverse repo investment volumes. We simplify the regression by assuming that all reverse repo investments have a similar impact. To estimate overall impact, 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.

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

Here the interpretation of λ is unambiguous. If λ is positive, CCPs' reverse repo investments increase the dispersion of Euro repo rates. If dealers' leverage-constrainedness is the transmission channel, rather than collateral scarcity, which is contained within the collateral country, we expect this coefficient to be positive.

Finally, we repeat the difference-in-differences regression (b) for spreads instead of rates.

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

As previously, $1W_i$ is 1 iff. the spread is taken between one-week repos and the uninteracted $1W_i$ term is omitted because it is collinear with the panel fixed-effects. If leverage ratio regulation does cause increased rates dispersion in the Euro repo market, then we expect λ_4 to be positive.

Results

The regression results in table 5 indicate that CCPs' reverse repo investments impact repo rates dispersion.

As explained, in regression (c) we regress CCPs' reverse repo investment volumes in both quote and base country on the rate spread between those countries. We find that a hypothetical CCP investment in the base country's reverse repos increases the spread by about 5.414 bp per standard deviation of investments. According to the safe asset literature, some (additional) liquidity or collateral benefits are embedded in the base assets. This supports the idea that regulatory-driven supply alters the convenience premium of safe assets.

Conversely, investments in the quote country have no significant effect. Comparing estimate sizes to the price impacts obtained in regression (a) indicates that something reinforces the price impact of the higher-quality base asset, whereas it counteracts the price impact of the lower-quality quote assets. This result points to a spillover effect between countries and/or to heterogeneous price impacts across countries. We interpret these results as follows: First, repos on safe assets are more affected by CCPs' reverse repo supply; second, additional repo supply increases the convenience premium of safe assets no matter which country CCPs invest in.

Indeed, regression results (d) show that a one standard deviation increase in total reverse repo investments, regardless of country, increases rate dispersion by 3.667 bp. We therefore conclude that reverse repo investments due to EMIR increase rate dispersion in the Euro repo market.

Employing the same diff-in-diff setting as in (b), we 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.

6.2 Forward Discount

Methods

In addition to rate levels and dispersion, we analyse the impact on the forward discount. The expectations hypothesis suggests that the rate of a tomorrow-next repo traded today is equal to the rate of the overnight repo traded tomorrow, plus a constant. This is the case because both repos have identical cash- and collateral-flows, but the tomorrow-next repo is traded one day in advance. Notice that both contracts have the same maturity, which ensures that the time frame for which the EH should hold and the return measurement period are identical. This provides a consistent framework for analysing the time variation in the term premiums (Longstaff, 1990). Further, the interbank repo market provides an ideal trading environment, for instance, in terms of anonymity and ample market liquidity. This reduces possible arbitrage opportunities and many kinds of frictions that can bias the formation of rational expectations (Longstaff, 2000a).

We proceed analogously to the rates dispersion (section 6.1) and capture the forward discount by a spread between repo rates. On this occasion, however, we take the spread between different one-day repos of the same country rather than between different countries. The panel index i then corresponds to a triplet (c, q, b), but this time the quote q and base b denote tenors while c specifies the country.

$$ForwardDiscount_{i,t} = Rate_{c,q,t} - Rate_{c,b,t}$$

Here we exclude one-week repos as they have a different maturity than the rest of the panel. This is necessary because we lack multiple one-week tenors with different forward periods. Further, a spread between a one-day and a one-week repo would incorporate term structure effects. However, the drawback is that the difference-in-differences equation (2) cannot be estimated without one-week repos. Furthermore, repos that are traded in advance will not show up on the balance sheet until they are settled. Hence, the forward period cannot be used to construct similar treated and non-treated groups. Analogously to the base country in section 6.1, we fix $q = ON$ because historically overnight repo rates have been the highest and because they are available for every country.

The resulting regression when substituting equation (a) into the forward discount is much simpler than that obtained for spreads. The reason being that the regulatory data $Reverse_{i,t}$ and $Bonds_{i,t}$ are not segmented according to tenors. In other words, these variables are the same for both tenors (base and quote), meaning that only one reverse repo and one bonds investment variable must be included. Only the $Orderflow_{i,t}$ in the controls must be expanded into $QuoteOrderflow_{i,t}$ and into $BaseOrderflow_{i,t}$ for the quote- and base-tenor respectively. Thus, our baseline regression for the forward discount is

$$ForwardDiscount_{i,t} = \lambda \cdot Reverse_{i,t} + \dots \quad \text{(f)}$$

If λ turns out to be non-zero, then CCPs' reverse repo investments influence forward discounts at the very short end of the term-structure.

Results

In table 6 below, we estimate how CCPs' reverse repo investments affect the forward discounts in the interbank repo market. Overall, the results provide evidence of how time-varying forward discounts affect short-term rates. Regression (f) shows that CCPs' reverse repos increase the forward discount by 1.23 bp per standard deviation of reverse repo investments. For cash borrowers/collateral lenders, this amounts to a larger forward discount as repo rates traded in advance are lower than overnight repo rates. Conversely, cash lenders/collateral borrowers face a larger forward premium.

These results suggest that CCP compliance with EMIR investment rules may lead to violations of the expectation hypothesis in the case of short-term interest rates. This holds true because repos with the same cash- and collateral-flows, but with different forward periods, are not affected equally by CCPs' reverse repo investments. These investment activities cause a spread between different one-day repos and hence drive a wedge between actual interest rates and expected interest rates one or two days earlier.

6.3 Order Flow

Methods

In addition to repo rates and spreads, we analyse how CCPs' reverse repo orders, which are ultimately submitted and settled over-the-counter, affect market imbalances in the electronically traded interbank market. In doing so, we aim to shed further light on the transmission channel of CCP' reverse repo investments to interbank repo rates.

The order imbalance of a financial market can be summarised by its order flow. If more market orders (as opposed to limit orders) involve buying rather than selling, then the price rises. Thus a well-accepted definition of order flow in the market microstructure literature is the total volume of buying market orders minus the total volume of selling market orders. Hence, if it is positive (negative), the order imbalance drives prices up (down). But when it comes to repo markets, this definition is at odds with market-specific terminology. The "buyer" of a repo contract buys the collateral at the purchase date and sells it back at maturity. As he is effectively a lender, "buy" market orders *decrease* repo rates.

To avoid potential confusion, we redefine the order flow for the repo market in terms of (cash-)borrowers and lenders, whose market orders drive rates up and down respectively:

$$Orderflow_{i,t} = Borrow_{i,t} - Lend_{i,t}$$

where $Borrow_{i,t}$ ($Lend_{i,t}$) is the total volume of borrowing (lending) market orders. We normalise the order flow by total trading volume to obtain an imbalance measure in the interval $[-1, 1]$, which we call $Ordershare_{i,t}$.

$$Ordershare_{i,t} = \frac{Borrow_{i,t} - Lend_{i,t}}{Borrow_{i,t} + Lend_{i,t}} = \frac{Orderflow_{i,t}}{Volume_{i,t}}$$

As borrowing and lending affects balance sheets differently, it is worth analysing the $Borrow_{i,t}$ and $Lend_{i,t}$ components separately. To this end, we adjust (1) by shifting one component of $Orderflow_{i,t}$ to the left-hand side and by leaving the other component as a control. This yields two regression equation, one for each side,

$$\begin{aligned} Borrow_{i,t} = FE(i) + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \alpha \cdot Borrow_{i,t-1} + \beta_b \cdot Lend_{i,t} \\ + \lambda_b \cdot Reverse_{i,t} + \epsilon_{i,t} \end{aligned} \tag{g}$$

$$\begin{aligned} Lend_{i,t} = FE(i) + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \alpha \cdot Lend_{i,t-1} + \beta_s \cdot Borrow_{i,t} \\ + \lambda_s \cdot Reverse_{i,t} + \epsilon_{i,t} \end{aligned} \tag{h}$$

where the controls are given by:

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

We expect that a repo dealer facing a large over-the-counter reverse repo order from CCPs not only cuts back on intermediating by entering repo positions in the interbank market, but also enters more reverse repo positions to offload the cash received from the CCPs. The former corresponds to submitting less borrowing limit orders, which do not show up in $Borrow_{i,t}$ because they are non-aggressive/liquidity providing. At least a part of the latter, however, will be achieved by submitting lending market orders. Hence, we expect λ_b, the influence of CCPs' reverse repo on borrowing market orders, to be non-significant, whereas λ_q, the influence on lending market orders, to be positive.

Other market participants will find that liquidity has remained constant for borrowers, whereas it has deteriorated for lenders. As the financial sector depends ever more on high-quality collateral, which can be obtained by lending in the repo market, banks may be expected to compete even more aggressively for the remaining limit orders. This reinforces the imbalance found above and lowers the $Ordershare_{i,t}$. We test this hypothesis by removing $Borrow_{i,t}$ and $Lend_{i,t}$ from the regression and by replacing the dependent variable with $Ordershare_{i,t}$.

$$Ordershare_{i,t} = FE(i) + \boldsymbol{\beta}^T \boldsymbol{X}_{i,t} + \lambda \cdot Reverse_{i,t} + \epsilon_{i,t} \tag{i}$$

where the controls are given by

$$\boldsymbol{X}_{i,t} = \begin{bmatrix} Ordershare_{i,t-1} \\ Bonds_{i,t} \\ CIP_{i,t} \\ VIX_{t-1} \end{bmatrix}$$

For these regression, we use the same panel as for regressions (a) and (b), which investigate rates.

Results

Table 7 shows that regression results highlight the influence of CCPs' reverse repo investments on interbank order flows.

Regressions (g) and (h) analyse the impact on the borrowing and lending sides of the market respectively. On the one hand, we find that CCPs' reverse repo investments do not significantly increase buy market orders. On the other, sell market orders increase by 0.562 billion per standard deviation of reverse repo investments.

This striking difference is consistent with large repo intermediaries being constrained by the combination of leverage ratio regulation and CCPs placing large amount of cash with them over reverse repos. If CCPs' counterparties were mostly liquidity takers, we would expect them to submit less borrowing market orders instead of reducing borrowing limit orders, which in turn would lead to a negative coefficient in regression (g). However, large dealers and liquidity providers want to keep a balanced book. They are therefore likely to offload the large one-sided position obtained from CCPs onto the interbank market. This will happen at least partially via market orders as an increasing supply of reverse repos competes for decreasing demand for repos. Hence, we find a positive coefficient in regression (h).

Our explanation is supported by regression (i) in that a one standard deviation investment of CCPs' reverse repos drives down order share by 0.034. These results are consistent with our hypotheses and nicely highlight the asymmetric impacts on the repo and on the reverse repo side of the market. As such, they make us confident that our proposed transmission channel of over-the-counter reverse repo orders on the short-term interbank interest rate is correct.

7 Order Flow Effects

TODO: Better subsection title & structure TODO: Motivate this subsection (transmission mechanism)

Methods

TODO:

- Bank-level order shares
- Bank panel
- Regression equation
- Motivate controls
- Expected results

Results

TODO:

- Interpret results

8 Robustness Tests

This section performs a series of robustness checks to verify the correctness of our results. We begin with an alternative specification of the difference-in-differences estimator in equation (2), which affects regressions (b) and (e). As discussed (section 2.1), there are differences in disclosure frequency across jurisdictions. Some banks need to report the leverage ratio at the end of every month, or an average over several month ends. It is therefore likely that the demand effects evident at the end of each quarter are also observable at the end of every month. We test this 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. Regression (b), used to test the demand effect on repo rates, exhibits a rate drop of -8.687 basepoints per standard deviation of investments with a P-value of 5.8%, compared to -26.383 bp with a P-value of 5.2% in the quarterly regression. Similarly, regression (e), used to test the demand effect on rates dispersion, exhibits an increase in the spread by 10.262 basepoints per standard deviation with a P-value of 5.4%, compared to 21.302 bp with a P-value of 1% in the quarterly regression. Therefore, we conclude that our results also hold true if balance sheet constraints at the end of each month are considered.

In section 3.4 we analyse the stationarity and persistence of our data. First, we show that a unit-root (or trend) in repo rates, stemming from monetary policy rates, cannot be rejected. As a robustness check, we subtract the ECB's deposit rate (the Bank of England's bank rate for Sterling segments) from $Rate_{i,t}$ to make the variation in repo rates stationary. We then repeat the supply (a) and demand (b) regressions. There is no need to repeat the same for the other regressions as they either work on spreads between repo rates that cancel out the policy rate to begin with, or do not work on repo rates at all. We find that all estimates remain the same in sign, magnitude and significance. Therefore, we conclude that the non-stationarity in repo rates does not affect our analysis.

Second, we cannot reject a unit-root in one country's reverse repo investment volumes, nor in two of our control variables (i.e., the VIX and bond purchase volumes). As a robustness check, we repeat our analysis by removing these two control variables and the panel segments of this country from all regressions. Qualitatively, our results remain the same and reveal that supply and demand effects become even more significant in many specifications. Only regressions (g), (h) and (i), which we used to analyse the impact of reverse repo investments on interbank order flows, are affected by this robustness test. Further, we find that borrowing (lending) volume is more (less) affected by reverse repo investments while the downward pressure on order imbalances is less significant compared to our original regressions. However, the sign of estimates stays the same. Overall, these additional analyses show that our results are not affected by potential non-stationarity of variables.

9 Conclusion

We analyse the effects of EMIR and Basel III regulation on short-term interest rates. Using unique and granular datasets of European repo transactions and clearing houses (CCP), we study the effects of clearing infrastructure increasing lending supply and banks decreasing borrowing demand. In the new regulatory setting, the former tends to (exogenously) increase lending supply (collateral demand) as prescribed by EMIR law while the latter decreases borrowing demand (collateral supply) through the leverage-constrainedness of repo dealers, particularly during specific reporting periods.

Three 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, regulation exacerbates repo spreads and lending pressure in the interbank market. These results suggest that regulation-induced scarcity alters some non-pecuniary (liquidity) benefits in safe assets and that regulatory effects are transmitted through intermediaries' constrainedness.

Our analysis is relevant to policy makers and market participants alike. For policy makers, 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 interbank repo rates below the central bank's deposit facility rate, which is a sign of safe asset scarcity and increased collateral demand (Duffie et al., 2015). Second, regulation-induced larger dispersion and downward pressure on rates may impede monetary policy effectiveness (Duffie & Krishnamurthy, 2016b). 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. This phenomenon has been attributed to various factors, including collateral scarcity due to central banks' extraordinary monetary policy instruments and market segmentation. Our findings offer an alternative explanation and point to prudential regulations, which 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. 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.[23]

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[23]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.

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Figure 1: Impact of Repo Trading on the Leverage Ratio

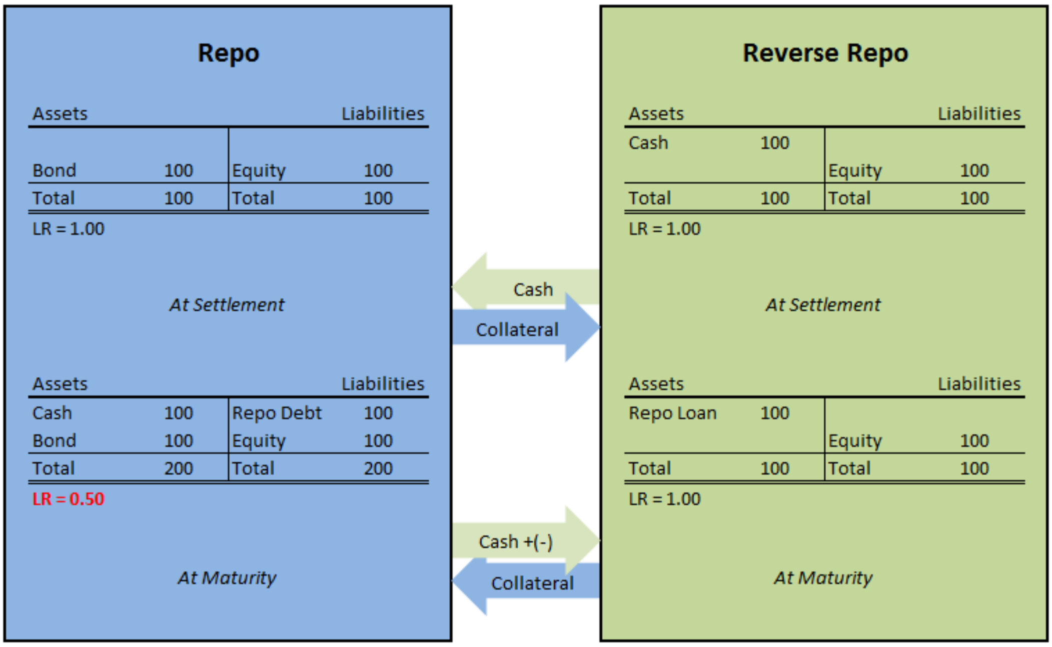


Figure 2: European Repo Rates

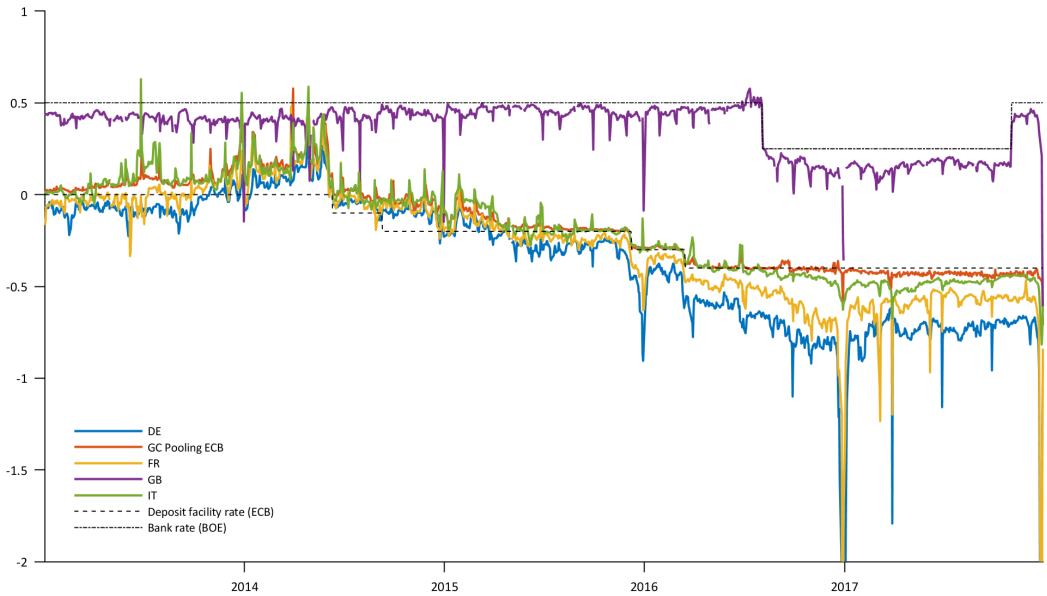
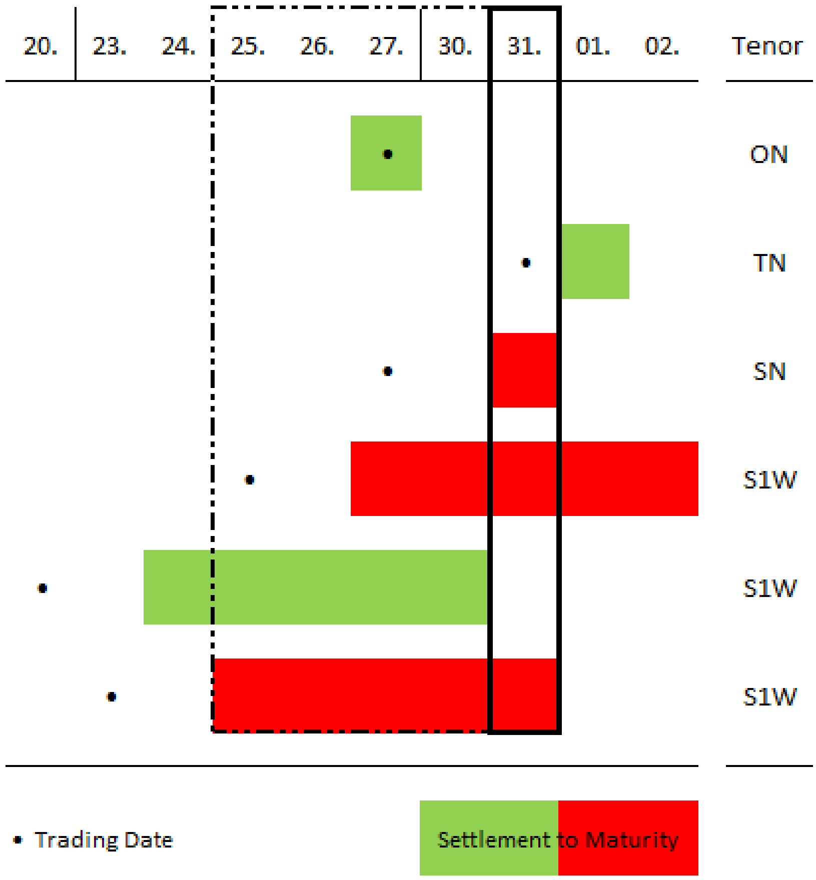


Figure 3: Balance Sheet Impact around Reporting Days



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: Descriptive Statistics

	Repo Market		Clearing Infrastructure		Other	
	$Rate_{i,t}$	$Orderflow_{i,t}$[1]	$Reverse_{i,t}$[2]	$Bond_{i,t}$[2]	$CIP_{i,t}$	VIX_{t-1}
Mean	−0.247	−1.428	– [2]	– [2]	−0.002	14.422
Std. Dev.	0.304	2.362	– [2]	– [2]	0.007	3.863
Skewness	−2.522	−1.095	0.746	0.415	−13.279	1.767
Kurtosis	43.401	17.195	4.125	2.799	257.670	7.645
AR(1)	0.874	0.413	0.796	0.989	0.353	0.941
Unit-root test[3]	0.169[4]	0.000	0.134[5]	0.391	0.000	0.132[6]

[1] Units are billion Euros. [2] Variables are standardized. [3] P-value for the Levin-Lin-Chu test. [4] Rates are stationary around a trend or the policy rate. [5] Unit-root is contained within a single country. [6] P-value for the Augmented-Dickey-Fuller test.

Table 3: Supply Effect on Rates

	$Rate_{i,t}$
	(a)
$Reverse_{i,t}$	-1.559^{**}
	(0.613)
$Orderflow_{i,t}$	0.215^{***}
	(0.031)
$Bonds_{i,t}$	-0.548^{*}
	(0.290)
$CIP_{i,t}$	154.322^{***}
	(57.255)
VIX_{t-1}	0.141^{***}
	(0.032)
$Rate_{i,t-1}$	0.914^{***}
	(0.015)
Fixed Effects	yes
Observations	12384
Segments	13
Clusters	221
R^2	0.934

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Note: Robust standard errors clustered at the segment and quarter are reported.

Table 4: Demand Effects on Repo Rates

	$Rate_{i,t}$
	(b)
$Reverse_{i,t}$	-0.973^{**}
	(0.398)
$Reverse_{i,t} \cdot 1W_i$	-6.652^{**}
	(3.079)
$Reverse_{i,t} \cdot BeforeEoQ_t$	0.120
	(0.437)
$Reverse_{i,t} \cdot BeforeEoQ_t \cdot 1W_i$	-26.383^{*}
	(13.499)
$BeforeEoQ_t$	-2.063
	(1.486)
$BeforeEoQ_t \cdot 1W_i$	-92.193^{*}
	(47.156)
$Orderflow_{i,t}$	0.221^{***}
	(0.030)
$Bonds_{i,t}$	-0.645^{**}
	(0.321)
$CIP_{i,t}$	126.569^{***}
	(37.820)
VIX_{t-1}	0.136^{***}
	(0.030)
$Rate_{i,t-1}$	0.911^{***}
	(0.015)
Fixed Effects	yes
Observations	12384
Segments	13
Clusters	221
R^2	0.879

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

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

Table 5: Effects on Repo Rate Dispersion

	$Spread_{i,t}$		
	(c)	(d)	(e)
$BaseReverse_{i,t}$	5.414***		
	(0.426)		
$QuoteReverse_{i,t}$	−0.580		
	(1.136)		
$TotalReverse_t$		3.667***	3.919***
		(0.312)	(0.214)
$TotalReverse_t \cdot 1W_i$			−2.229***
			(0.691)
$TotalReverse_t \cdot BeforeEoQ_t$			−1.898**
			(0.760)
$TotalReverse_t \cdot BeforeEoQ_t \cdot 1W_i$			21.302***
			(8.152)
$BeforeEoQ_t$			3.421***
			(0.685)
$BeforeEoQ_t \cdot 1W_i$			4.255*
			(2.519)
$BaseOrderflow_{i,t}$	−0.093***	−0.075***	−0.076***
	(0.022)	(0.020)	(0.019)
$QuoteOrderflow_{i,t}$	0.146***	0.127***	0.129***
	(0.023)	(0.022)	(0.021)
$BaseBonds_{i,t}$	−1.784***	−0.454	−0.584
	(0.263)	(0.334)	(0.304)
$QuoteBonds_{i,t}$	0.230	−0.081	−0.186
	(0.372)	(0.304)	(0.293)
$CIP_{i,t}$	−130.766***	−113.795***	−58.399***
	(41.470)	(38.108)	(14.644)
VIX_{t-1}	−0.168***	−0.163***	−0.162***
	(0.024)	(0.023)	(0.023)
$Spread_{i,t-1}$	0.506***	0.480***	0.471***
	(0.025)	(0.024)	(0.024)
Fixed Effects	yes	yes	yes
Observations	13503	13503	13503
Segments	15	15	15
Clusters	255	255	255
R^2	0.484	0.495	0.512

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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

Table 6: Effects on Forward Discounts

	$ForwardDiscount_{i,t}$
	(f)
$Reverse_{i,t}$	1.230**
	(0.516)
$BaseOrderflow_{i,t}$	0.155***
	(0.048)
$QuoteOrderflow_{i,t}$	0.336***
	(0.059)
$Bonds_{i,t}$	−0.298
	(0.410)
$CIP_{i,t}$	42.575***
	(14.117)
VIX_{t-1}	−0.008
	(0.029)
$ForwardDiscount_{i,t-1}$	0.159***
	(0.029)
Fixed Effects	yes
Observations	6631
Segments	7
Clusters	119
R^2	0.039

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

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

Table 7: Effects on Order Flows

	$Borrow_{i,t}$	$Lend_{i,t}$	$Ordershare_{i,t}$
	(g)	(h)	(i)
$Reverse_{i,t}$	0.071	0.562***	−0.034***
	(0.117)	(0.089)	(0.009)
$Borrow_{i,t}$		0.101***	
		(0.021)	
$Lend_{i,t}$	0.057***		
	(0.016)		
$Bonds_{i,t}$	0.026	0.083	−0.006
	(0.048)	(0.065)	(0.007)
$CIP_{i,t}$	3.110	−1.000	0.755***
	(2.005)	(1.997)	(0.276)
VIX_{t-1}	−0.012***	−0.002	−0.001
	(0.004)	(0.005)	(0.001)
$Borrow_{i,t-1}$	0.741***		
	(0.022)		
$Lend_{i,t-1}$		0.726***	
		(0.024)	
$Ordershare_{i,t-1}$			0.215***
			(0.018)
Fixed Effects	yes	yes	yes
Observations	12490	12490	12490
Segments	13	13	13
Clusters	221	221	221
R^2	0.954	0.959	0.045

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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

Table 8: Effects on Bank-level Order Flows

	$MarketBorrow_{i,t}$	$LimitBorrow_{i,t}$	$MarketLend_{i,t}$	$LimitLend_{i,t}$
	(j)	(k)	(l)	(m)
$Reverse_t$	0.00240*	0.00172	−0.00414***	0.00018
	(0.0014)	(0.00155)	(0.00158)	(0.00138)
$Reverse_t \cdot Counterparty_i$	−0.00323**	−0.00465***	0.00740***	0.00058
	(0.00166)	(0.00183)	(0.00204)	(0.00176)
$Bonds_t$	−0.00183	0.00029	0.00079	0.00042
	(0.00141)	(0.00156)	(0.00171)	(0.00142)
$OrderShare_{i,t}$	0.13782***	−0.13406***	−0.15038***	0.16934***
	(0.00830)	(0.00920)	(0.00998)	(0.00902)
$\Delta Rate_t$	0.01632	−0.00530	−0.00202	−0.00624
	(0.00995)	(0.01285)	(0.01388)	(0.01183)
$log(Volume_t)$	−0.00901	0.03368***	−0.00984	−0.01442
	(0.00983)	(0.01079)	(0.01191)	(0.01059)
$EffectiveSpread_t$	−0.00039	0.00027	0.00009	0.00004
	(0.00043)	(0.00047)	(0.00047)	(0.00045)
$Volatility_t$	0.00037	−0.00037	−0.00029	0.00021
	(0.00047)	(0.00051)	(0.00052)	(0.00049)
CIP_t	0.22925**	−0.14261	−0.26934**	0.15851
	(0.09903)	(0.10239)	(0.12306)	(0.11295)
VIX_{t-1}	−0.00010	−0.00052*	0.00091***	−0.00033
	(0.00029)	(0.00029)	(0.00032)	(0.00027)
$MarketBorrow_{i,t-1}$	0.34471***			
	(0.00955)			
$LimitBorrow_{i,t-1}$		0.47129***		
		(0.00982)		
$MarketLend_{i,t-1}$			0.44545***	
			(0.00947)	
$LimitLend_{i,t-1}$				0.35277***
				(0.01001)
Fixed Effects	bank & month	bank & month	bank & month	bank & month
Observations	67386	67386	67386	67386
Banks	226	226	226	226
Clusters	118	118	118	118
R^2	0.367	0.570	0.494	0.388

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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