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Regulatory effects on short-term interest rates[☆]

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ABSTRACT

We analyze the effects of prudential regulation on short-term interest rates. The European Market Infrastructure Regulation (EMIR) induces clearing houses (CCPs) to *supply* large amounts of cash in reverse repurchase agreements (repos). Basel III, in contrast, disincentivizes the borrowing *demand* by tightening banks' balance sheet constraints. Using unique regulatory data of CCP investment activity and repo transactions, we find compelling evidence for both the 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 due to the new regulatory framework.

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1. Introduction

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

In addition to these structural changes, some puzzling patterns emerge in money markets. As illustrated in Fig. 1,

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

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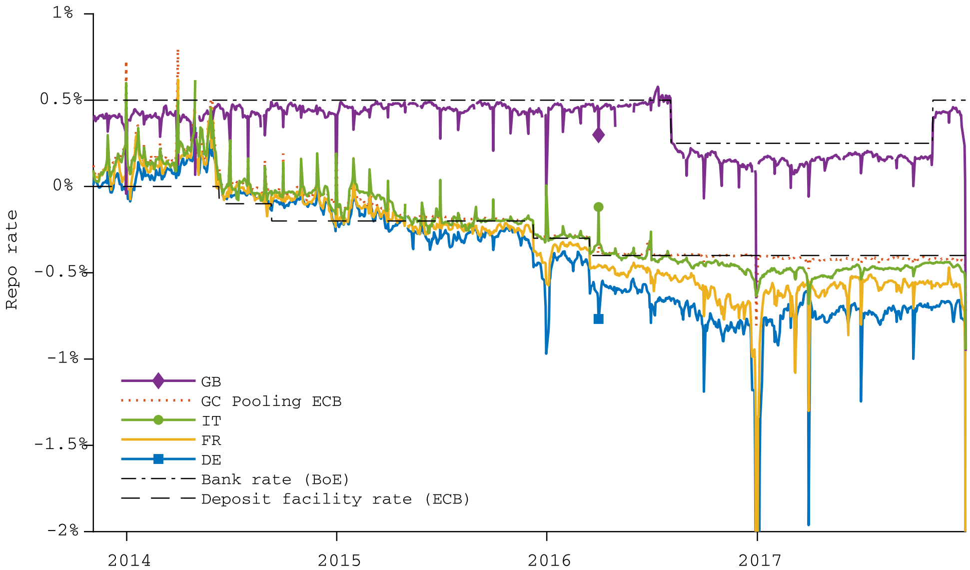

Fig. 1. European repo rates.
The figure presents the evolution of European repo rates from November 4, 2013 to December 29, 2017. For each collateral country (given by first two letters of the collateral ISIN) daily volume-weighted average repo rates are shown. In the "GC Pooling ECB" market segment, all collateral eligible in the ECB's collateral framework can be pledged. The dashed lines represent central bank deposit rates for the euro (ECB) and pound (Bank of England).

European repo rates have dropped below the central bank deposit rate since 2015, exhibiting wider cross-sectional dispersion and marked declines on the reporting days of the Basel III leverage ratio (Bank for International Settlements, 2017). These issues have gained attention from regulators and practitioners, raising several compelling questions: How does the new regulatory framework in banking and financial market infrastructures affect the repo market? Has it created unintended consequences by bringing down and spreading out short-term interest rates? And if it does, why?

To address these important questions, we analyze unique regulatory data from the investment activity of UK CCPs, together with a comprehensive dataset of European repos, covering the period from November 2013 to December 2017. We identify two key regulatory effects: one affecting the repo supply (or reverse repos) and the other affecting the repo demand. On the supply side, the European market infrastructure regulation (EMIR) requires European CCPs to turn their unsecured cash holdings from the collection of margins into highly liquid securities. In practice, CCPs obtain these securities by entering into reverse repos (i.e., they lend cash against collateral). We find that the repo supply enforced by this regulation puts significant downward pressure on short-term interest rates. On the demand side, the Basel III leverage ratio entails that repos expand the balance sheet of financial intermediaries, whereas reverse repos do not. We find that CCPs' downward pressure on short-term rates strengthens during the regulatory reporting dates when the leverage ratio bites banks' repo cash borrowing demand the most. To provide insight on the transmission mechanism, we show that those banks borrowing from CCPs offload their liquidity surpluses by lending more in the interbank market.

A better understanding of how new regulations affect short-term interest rates is relevant for regulators who have imposed a number of regulatory constraints on banks with unknown effects and interactions (e.g., Coeuré, 2017; Haldane, 2017). While new prudential policies strengthen financial stability, regulations, such as the Basel III leverage ratio, might have created unintended effects, such as disincentivizing repo intermediation (Duffie, 2016),[2] inducing collateral scarcity (Coeré, 2012) and window-dressing at the end of reporting periods (Bank for International Settlements, 2017).[3] Furthermore, the Dodd–Frank Act and EMIR implementation in the United States and Europe, respectively, have made central clearing mandatory for a large number of interest rate swaps and credit default swaps (CDS), thus making CCPs large actors in financial markets. Understanding these issues is crucial for phasing-in and redesigning the regulatory framework to achieve the desired level of market efficiency and financial stability (Duffie, 2018). Our study is also relevant to cen-

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

[3] For example, the Bank for International Settlements (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 behavior 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."

tral banks as many monetary policies are implemented through short-term rates.

Our first contribution is to show the causal effect of the new regulation governing clearing infrastructures on the supply side of the repo market. The main function of CCPs is to reduce counterparty risk by collecting initial margin and default fund contributions. As a result, CCPs hold vast amounts of cash. For instance, the total cash received daily by the top 10 European CCPs in 2016 exceeded EUR 140 billion.[4] EMIR states that at least 95% of any cash position that remains in a CCP's margin accounts or default fund overnight must be invested into reverse repos or government bonds or deposited with a central bank (see Articles 44–45 of EMIR (European Commission, 2013, p. 63). For further details, see Section 2.1). This means that clearing houses are required to reinvest cash in a given set of highly safe and liquid assets available on the market on a daily basis. In practice, the CCPs in our sample comply to the EMIR requirement by lending repo cash for obtaining and holding exclusively high-quality collateral in the OTC bilateral segment of the repo market. The investment of European CCPs in the reverse repo market is substantial. For instance, out of the EUR 140 billion cash received by the top 10 European CCPs in 2016, about EUR 60 billion were invested daily in reverse repos according to CPMI-IOSCO disclosures. This represents a sizeable amount compared to the total daily borrowed volume of about EUR 300 billion in the euro interbank repo market. Therefore, the supply hypothesis arises: the additional cash supply due to CCPs' reverse repo investments lowers interbank repo rates.

To test the supply hypothesis, we perform a series of panel regressions with fixed effects for the country of the collateral asset. Daily excess rates, defined as the difference between the interbank repo rate and the central bank deposit rate, are regressed on aggregate CCPs' investment on reverse repos. We note that in addition to being determined by regulation and by the amount of cash accumulated on CCPs' margin accounts, CCPs' repos are conducted in the OTC segment, while we analyze the impact on interbank rates. Furthermore, the main purpose of CCPs is to fulfill the regulation requirements rather than to profit from (transient) investment opportunities. Hence, it is reasonable to assume that the CCP investment is exogenous to the interbank repo market. We control for other potential factors including interbank order flow (i.e., borrower-initiated minus lender-initiated repos) that should determine price formation according to microstructure theory, risk variables accounting for possible margin procyclicality, CCPs' purchases in the cash bond market, which can induce indirect effects on short-term rates such as "specialness," quarter-end ("window-dressing") effects, and quantitative easing (QE) effects that can create collateral scarcity and excess liquidity. The main finding is that to conform to new regulation, CCPs' repo cash lending exerts a pervasive and systematic downward pressure on short-term rates, thus supporting the supply hypothesis. We conservatively estimate that about 1.4–4.5% of the average daily variation in repo rates is driven by CCPs' repo cash lending.[5]

Our second contribution is to show how the leverage ratio affects the demand side of repo markets, thereby sharpening its identification compared to previous work. To do this, we exploit the interaction between the EMIR and Basel III regulations. The main idea is to analyze the impact of the exogenous variation of CCPs' cash supply on the downward-sloping demand curve for repos during the Basel III leverage ratio reporting periods. Note that only repo contracts and not reverse repos expand bank's balance sheets (see Section 2.2 for details). Hence, banks are less inclined to demand repos, whereas repo supply remains essentially unaffected.[6] The demand hypothesis therefore stipulates that repo demand drops during leverage ratio reporting periods.

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

In the remainder of our paper, we delve into the transmission mechanism of prudential regulation. To do this, we analyze which repos and banks are affected the most. About repos, we carry out a panel regression analysis on yield differentials between them. Specifically, we compute the daily difference between the highest and lowest rates, that is, a long-short (yield) spread. We find that the purchase of collateral assets by CCPs widens yield spreads and that the lowest rate (of the short repo) is negatively affected the most. This finding delivers two insights: On the one hand, it supports the idea that CCPs lend cash (purchasing safe assets) to fulfil the prudential regulation rather than other opportunistic or speculative motives (that would be consistent with a positive coefficient). On the other hand, from the perspective of the safe asset literature, this finding suggests that regulation chiefly affects repos bearing the largest convenience premia (i.e., offering highest safety or liquidity benefits). Second, we perform panel regressions at the bank level. About banks, we carry out a panel regression analysis on daily borrowing and lending of each individual bank. By entering a bilateral

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

[5] Any market participant, not just CCPs, making these investments would affect 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.

[6] Note that the leverage ratio is an unweighted risk measure, suggesting that it is the balance sheet size rather than the asset quality that matters.

(OTC) repo contract with a CCP, a bank suffers from a cash surplus, a shortage of high quality liquid assets (HQLA), and an expansion of the balance sheet. We find that the banks which are the borrowing counterparties of the CCPs (i.e., those banks selling (borrowing) collateral (cash) to (from) CCPs), tend to offset any consequent cash surpluses and asset shortages by lending more in the interbank repo market.

We contribute to at least three strands of the literature: First, to the growing literature on intermediary asset pricing (e.g., He and Krishnamurthy, 2013; Adrian et al., 2014; He et al., 2017). We do so by showing that regulations have created new and important market participants (i.e., clearing houses), that affect how financial intermediaries price and trade short-term rates.[7]

Second, we contribute to the literature on repos, which represent an important category of safe assets (Gorton, 2017).[8] Only a few studies analyze the regulatory effects on repo rates.[9] Our study is the first to highlight how the new mandatory framework including EMIR contributes to dragging down repo rates (below central bank deposit rates[10]) and widening their dispersion. The regulatory effects we identify represent a new explanation for low and dispersed short-term rates that complements narratives on collateral scarcity and QE impacts, as we demonstrate empirically.[11]

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

The remainder of the paper is organized as follows: In Section 2, we introduces the regulatory reforms. In Section 3, we present our datasets. In Sections 4 and 5, we analyze the supply and demand hypothesis, respectively. We provide additional analyses in Section 6. Concluding remarks are in Section 7.

2. Regulatory context

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

2.1. European market infrastructure regulation

In July 2012, the European Union issued the EMIR, which lays down the regulatory framework for OTC derivatives, CCPs, and trade repositories. Among other things, it introduced clearing requirements for OTC derivatives and uniform standards for the operation of European CCPs. Of particular interest are the requirements concerning CCP's handling of the cash collected daily as part of their risk management procedures in the form of initial margin and default fund contributions. They require CCPs to hold at most 5% on average on unsecured deposits, which protects them against counterparty risk. In practice, complying with this regulation requires CCPs to invest their cash daily into reverse repos, government bonds, and/or when available, central bank deposits.[14]

CCPs collect initial margin daily (or sometimes intraday) as a protection against counterparty risk. Initial margin calculations are risk-based, reflecting the size and the riskiness of clearing members' portfolios. Data from public disclosures indicate that about 45% of the initial margin posted to the top 10 European CCPs in 2016 was in cash (see Fig. 2). This share remained essentially constant throughout our sample period, suggesting that unconventional policies, including QE and central bank liquidity provisions, have not led banks to pledge more cash as collateral. These figures clearly indicate that the cash that needs to be invested daily by CCPs is considerable. The total cash received daily by the top 10 European CCPs from 2015 to 2017 exceeded on average EUR 150 billion.[15]

The enormous amount of cash held by CCPs indicates the importance of the phenomenon that we study in this paper. It reflects the sheer size of the markets CCPs clear and the mandatory central clearing of standardized OTC derivatives first introduced in the US and EU in 2013 and 2016, respectively. At the end of 2016, the outstanding notional in the OTC derivatives market amounted to USD 544 trillion, of which 61% was centrally cleared for interest rate derivatives, 28% for CDS, and minuscule for FX, commodity and equity derivatives (e.g., Financial Stability Board, 2017a,b. As central clearing mandates are phased-in, the proportion of the centrally cleared market segment, and

[7] Several recent studies examine the regulatory effects on market liquidity (e.g., Adrian et al., 2017; Bicu et al., 2017; Trebbi and Xiao, 2017) and on risk-taking (Acosta-Smith et al., 2018) and arbitrage (Du et al., 2018).

[8] Several recent studies analyze repo markets in Europe (e.g., Mancini et al., 2016; Boissel et al., 2017) and in the US (e.g., Gorton and Metrick, 2012; Copeland et al., 2014; Krishnamurthy et al., 2014).

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

[10] Our study highlights that EMIR exerts a downward pressure on rates that contributes to exceptionally low interest rates. To explain why interbank repo rates remain below central bank deposit rates, collateral scarcity, limits to arbitrage, and/or market segmentation is needed (e.g., Bech and Klee, 2011; Schaffner et al., 2019), which lies outside the scope of this study.

[11] Some recent studies examine the effects of unconventional monetary policies on repo markets (e.g., Pelizzon et al., 2018; Arrata et al., 2020; Corradin and Maddaloni, 2020).

[12] See, for instance, Arora et al. (2012), Loon and Zhong (2014), Duffie et al. (2015), and Du et al. (2016). Cenedese et al. (2020) studying interest rate swaps represents an exception.

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

[14] See the Article 47 of EMIR and Commission Delegated Regulation (EU) No 153/2013 (European Commission, 2013, p. 63, Article 45). The latter says that "where cash is maintained overnight [...] not less than 95% of such cash, calculated over an average period of one calendar month, shall be deposited through arrangements that ensure the collateralisation of the cash with highly liquid financial instruments [...]."

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

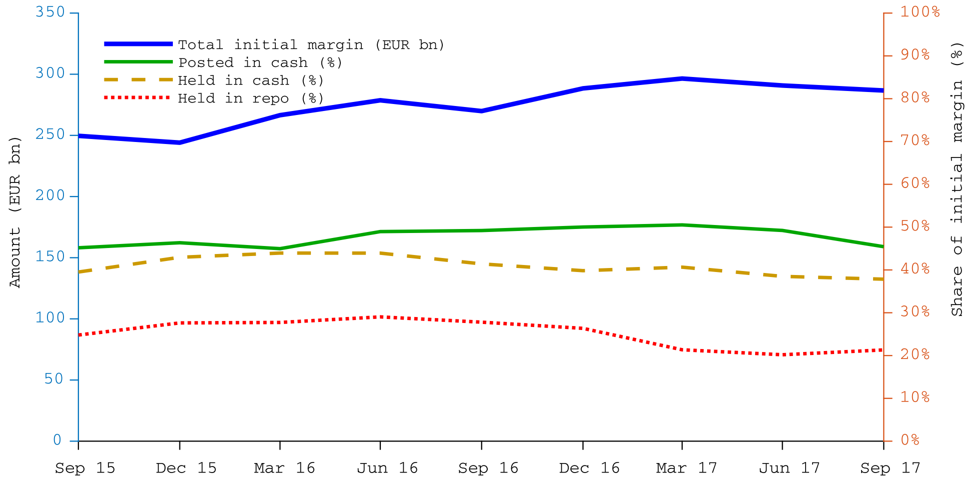

Fig. 2. Initial margin composition.
The figure presents the evolution of aggregated initial margin requested by the top 10 EMIR-regulated CCPs from their clearing members. It also shows the fraction of initial margin that clearing members satisfied by posting cash. Furthermore, it shows how CCPs held this cash, i.e., the fraction held in any cash-instrument (i.e., central bank, commercial deposits, or reverse repo) and in reverse repos only. The source of the data is the CPMI-IOSCO Public Quantitative Disclosures by European CCPs from 2015 to 2017.

consequently the size of CCP investment, is expected to continue to grow.

Our main interest lies in CCPs' investment in reverse repos. We consider this investment as "mechanical" and exogenous to the repo market since it is driven by the need for regulatory compliance with EMIR. Note that the size of CCP investment is solely driven by the margin posted by clearing members. Margin tends to increase with portfolio volatility and the net position of a clearing member against the CCP. As discussed earlier, the composition of initial margin has been fairly stable since 2015 (when public data became available), with cash accounting for about 40%, with the rest being securities. Furthermore, clearing members have no incentive to deposit excess cash with the CCP, as there is typically a charge, that is a spread on the overnight benchmark index (e.g., the EONIA for euro-denominated cash).

The CCPs have the option to substitute reverse repos with other safe assets, such as government bonds. However, this is a less efficient option for two reasons. First, purchasing individual securities (specific ISIN) from the illiquid bond markets is costlier than obtaining general collateral (GC) in a reverse repo. Second, EMIR (European Commission, 2013) requires that the average time-to-maturity of CCP investment portfolios does not exceed two years, an important constraint for purchasing individual bonds. In Fig. 2, the gap between cash posted as initial margin and cash held by CCPs reflects this substitution towards bonds or other non-cash assets. Although it increased throughout 2016, on aggregate, CCPs never convert more than 10% of the posted cash into bonds. Nonetheless, to err on the side of caution, all our regressions include the CCP bond investments as a control variable.

Another option for CCPs is to deposit cash at central banks. However, this alternative is not always available, while when it exists, it can come with strict requirements. This is particularly the case with the CCPs in our sample. The Sterling Monetary Framework is built around using a reserves averaging system. Participants set a target for the average reserves they will hold over the next maintenance period. Holding average reserves outside a narrow range around this target attracts a charge (Bank of England, 2015). Although the reserves averaging scheme was suspended for banks in 2009, it still applies to UK CCPs that must hold daily average reserves between 99% and 101% of said target. Missing the target gives rise to a hefty charge of 200 bps (Bank of England, 2019). Given the volatile nature of initial margin and the cash held by CCPs, the use of central bank deposits by UK CCPs as a mean to comply with the EMIR requirement is rather restrictive. The usage of central bank deposits among the top 10 European CCPs is highlighted in Fig. 2 by the gap between all cash held by CCPs and the share they held in (reverse) repos. More than 50% of this cash is placed into repo markets, and more importantly, this share remains almost constant throughout our sample period, making a potentially endogenous substitution of reverse repos, with central bank deposits unlikely to affect our analysis.

Hence, in practise the CCPs in our sample comply with the EMIR by investing the cash received on margin accounts into the reverse repo market. However, two further issues must be considered to assess the exogeneity of these investments with respect to repo rates. First, the exogeneity of CCPs' reverse repo investments depends on the exogeneity of cash margin deposits as the latter can drive the former. Second, even though the total amount of reverse repo investments is exogenous, we must establish whether the CCPs' allocation of reverse repos across different collateral groups is exogenous to repo rates as well.

Clearing members can actively choose whether to post government bonds or cash as margin collateral. This choice might depend on repo rates and hence endogenize CCPs' reverse repo investments. During our sample period, collateral scarcity, likely due to the ECB's PSPP, has increased and depressed repo rates (Arrata et al., 2020). Due to this scarcity, it is plausible that clearing members became more reluctant to cover margin calls with government bonds, increasingly posting cash instead. Such trading behavior would manifest itself in a rising share of cash in the composition of margin deposits. However, by investigating CCPs' CPMI-IOSCO quantitative disclosures, we observe this share remained stable around 45–50% throughout our sample period (see Fig. 2) and therefore conclude that this channel is unlikely to significantly affect our results. Nevertheless, to err on the side of caution, we additionally guard against this possible channel and omitted variables by including PSPP volumes in our regressions.

At the end of each quarter, clearing members might have an additional incentive to substitute government bonds with cash on their margin accounts. By pulling government bonds from margin accounts and replacing them with cash, clearing members could pledge them as collateral in the repo market and profit from the exceptionally low repo rates observed at quarter ends. This would increase cash collateral (and by extension, CCPs' reverse repo investments) at quarter ends when repo rates are low. Furthermore, this short-lived substitution would not be detectable with the quarterly CPMI-IOSCO disclosures. However, by inspecting quarter-end patterns in our confidential data, we find that actual reverse repo investments performed by CCPs are inconsistent with this channel, that is, there is no increase in CCP investments at quarter ends throughout the whole sample period. If anything, the CCPs in our sample slightly decrease their repo activity at quarter ends. What is more, the presumed trading behavior of clearing members is at odds with the conventional wisdom and recent research about quarter-end dynamics in repo markets (Schaffner et al., 2019). The observed window-dressing behavior at quarter-ends leads to negative spikes in repo rates because banks have a high incentive to decrease their repo borrowing activity to improve their leverage ratio (see more details in Section 2.2) and keep high-quality assets unencumbered to improve the liquidity coverage ratio. The putative trading strategy (substituting collateral for cash margins) therefore comes with high regulatory costs and is unlikely to be pervasive throughout the market. Although this channel is unlikely to affect our results, we remove every last day of the quarter from our regressions, which generally works against our results. As an additional robustness test, we remove the last weeks of all months in Section 6.3. This ensures that all incentives to window-dress coming from either the leverage or the liquidity coverage ratio are removed, which of course also includes any short-term margin substitution at quarter-ends.

Lastly, a potential concern could be that the investment decisions of CCPs themselves endogenize the allocation of reverse repos across collateral groups, even though the total size of investments is exogenous. This would happen if CCPs act opportunistically, by predominantly lending (borrowing) money within those collateral segments that exhibit the highest (lowest) repo rates. This argument is flawed for two reasons. First, it implies that CCPs mostly purchase (sell) least (most) safe collateral, which is fully inconsistent with their policy and with the regulation to which they are subject.[16] Second, this channel induces a positive correlation between repo rates and CCPs' reverse repo investments, thereby working against our hypotheses and main findings. In fact, in both our supply and demand hypotheses, we postulate that a negative effect on repo rates originates from CCPs investments, and we provide compelling evidence supporting them. Furthermore, when we analyze the spread between high and low repo rates in Section 6.1, we find that CCPs' investments widen the spread, whereas the presumed channel would imply the opposite [i.e., a downward (upward) effect on the high (low) repo rates], thereby reducing the spread. Hence, we conclude that this channel is unlikely to affect our results and even if it does, it works against them.[17]

Looking beyond the CCPs in our sample, we find that reverse repo investments to comply with EMIR requirements are both sizeable and common. Even if it varies across CCPs, in Europe the aggregate CCP investment in reverse repos is substantial and fairly stable across time.[18] Public data from the CPMI-IOSCO quantitative disclosures of the top 10 EU CCPs in the first quarter of 2016 suggest that their aggregate daily investment in reverse repos was in excess of EUR 60 billion or about 45% of the total cash received by these CCPs. With some variations reflecting regulatory differences, a similar picture emerges in other jurisdictions. For example, the 2016:Q1 CPMI-IOSCO public disclosures suggest that the cash deposits of the major US CCPs were almost entirely held at commercial banks (at unsecured deposits or reverse repos). In more recent years (2019), the picture is mixed. The ICE Clear US, the largest CCP in the CDS market, invests its cash mainly (about 70%) in the reverse repo market and the rest in domestic government bonds. The CME Group, the Options Clearing Corporation (OCC), and the DTCC, hold about 50–60% of their cash as central bank deposits, and the rest at commercial banks (with about 20% of total cash invested in reverse repos).

2.2. Basel III

The Basel III framework, announced in 2010, was developed by the Basel Committee on Banking Supervision

[16] For example, Article 47 of EMIR states that a CCP shall invest its financial resources only in cash or in highly liquid financial instruments with minimal market and credit risk. "Principles for Financial Markets Infrastructures" (Bank for International Settlements, 2012) state that infrastructures, such as CCPs, should rely on investments "that are readily available and convertible into cash with prearranged and highly reliable funding arrangements, even in extreme but plausible market conditions." Very safe and liquid positions are also necessary in stress tests ran by the European Securities and Markets Authority (2019).

[17] To provide empirical support against the above-mentioned endogeneity concerns, we carry out a bivariate daily vector autoregressive (VAR) analysis in Section 6.1 that endogenizes CCPs reverse repo investments along with the (volume-weighted) repo market rate. The estimated VAR-coefficients show that the CCPs do not react to repo rates.

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

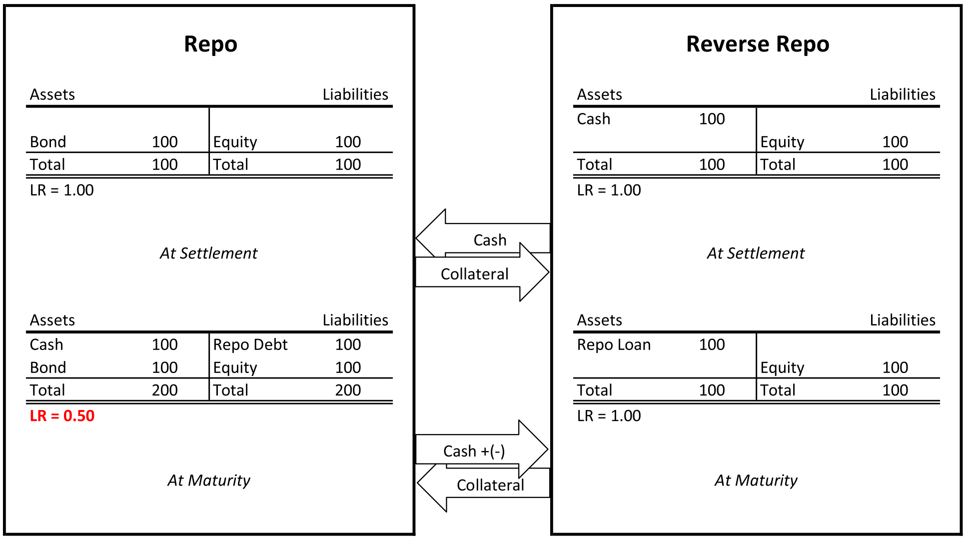

Fig. 3. Impact of repo trading on the leverage ratio.
This figure illustrates how entering a repo contract affects traders' balance sheets, starting out from a zero position in repos. The upper half shows the borrower's and lender's balance sheets before the trade, whereas the lower half shows balance sheets between the settlement and maturity date. Trading a repo (borrowing cash) extends a trader's balance sheet. Conversely, trading a reverse repo (lending cash) does not. This is because the collateral pledged stays on the balance sheet of the cash borrower.

(BCBS) to strengthen the regulatory framework for banks. Capital and liquidity requirements are central to Basel III. Particularly important for our analysis is the leverage ratio (i.e., the ratio of tier 1 capital to total exposures) that was introduced as a non-risk-weighted capital ratio in an attempt to limit the overly build-up of leverage in banks' balance sheet.

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

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

In many jurisdictions, including Europe, the treatment of repo market exposures in the leverage ratio calculation is asymmetric. As illustrated in Fig. 3, 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. Conversely, reverse repos do not enter the leverage ratio calculation because the lender is not exposed to the risk of collateral (except in the case of a default). Consequently, the collateral is not added as an asset in the bank's balance sheet, while the cash lent is removed from the asset side and replaced by a repo loan receivable.

As a result, banks' intermediation involving repo demand (as opposed to repo supply, or reverse repos) is constrained by the leverage ratio (e.g., Domanski et al., 2015; Duffie, 2016). This applies in particular to global systemically important banks (G-SIB) that receive a capital surcharge in addition to the minimum leverage ratio. We expect the impact of the leverage ratio in the repo market to grow around the reporting end-of-quarter dates (Munyan, 2015), a manifestation of the decreasing demand for repos when the leverage ratio bites banks' balance sheet the most. The liquidity coverage ratio (LCR) can also produce window-dressing effects. However, these effects are very limited in our setup, which is especially well-suited to control for the LCR for at least two reasons. First, all collateral assets are Level 1 high quality liquid assets (HQLA) and therefore unaffected by the LCR rules (c.f., Bank for International Settlements, 2017, pp. 27–28). Second, all maturities are shorter than the 30-day LCR cut-off time. Hence, it is essentially impossible to use the repo contracts under inspection to adjust the LCR at quarter-ends. However, we acknowledge

Table 1
Breakdown of the repo dataset.
This table shows the breakdown of the repo transactions by the trading venue from which they were obtained, by their clearing arrangement (centrally cleared or bilateral), currency, origin country of the collateral (first 2 letters of the ISIN), and by tenor. The breakdown is given in terms of the number of transactions and the nominal amount in euro. The dataset contains all repo transactions conducted on the three major electronic platforms in Europe between November 4, 2013 and December 29, 2017.

	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 Repo	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
>-day	0.25	12.7	1.9	3.9

that we still might capture a small impact from the LCR.[19]

3. Data

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

3.1. Repo interbank market

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

Table 1 shows a breakdown of the dataset by trading venue, clearing, currency, the collateral's country of origin (the first two letters of ISIN), and maturity. Two remarks are in order here. First, volumes in sterling have been converted to euros, at the exchange rate of 1.12 EUR/GBP (only for the purpose of this table). Second, a repo is collateralized 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.

Table 1 reveals that the vast majority of repos in our sample are centrally cleared with a one-day maturity. As a CCP assumes all counterparty credit risk, these trading venues are able to provide fully anonymous repo trading. This makes the electronically traded repo market an ideal research ground for short-term interest rates as it naturally excludes many confounding factors. For example, every trader faces the same counterparty credit risk as exposure is only to the CCP. Similarly, relationship trading, bargaining power, and asymmetric information issues (e.g., about counterparty credit risk) are not important as all parties see the same anonymized central limit order book and cannot select specific counterparties.

After grouping repo transactions by tenor and collateral country, we focus on the most liquid groups in the interbank market. This produces six countries and four tenors (ON, TN, SN, and S1W).[20] 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,

[19] Arguably, a minor and indirect effect could arise from repo contracts outside our sample that are subject to regulatory arbitrage (e.g., bilateral repos secured by corporate bonds and/or with tenors longer than one month). As these repos sensitive to LCR represent a small market share, it is fair to assume that they should not affect interbank rates.

[20] 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)).

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. Note that both general collateral as well as specific collateral are included in each of these segments and are used to conduct our main analysis. However, a sub-sampling exercise in Section 6.3 clearly shows that our results do not depend on the inclusion of specific collateral repos.

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

Fig. 1 displays the evolution of European repo rates. Three facts are worth noting: First, the repo market is characterized by two regimes. While in the first part of the sample period repo rates tend to follow the respective central bank deposit rate, in the second part they 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, exhibits much lower rates than a relatively less safe one. Third, strong seasonalities are evident at the month-end (quarter-end) and entail lower rates and larger rate dispersion.

The first pattern (i.e., interbank repo rates trading below the central bank deposit rate) may seem puzzling as banks could just borrow cash in the repo market and then deposit it with the respective central bank to make a safe profit. A sufficient quantity of this near-arbitrage trading strategy would keep interbank rates strictly tied to the central bank deposit rate.[21] The second pattern indicating wider cross-sectional dispersion of repo rates suggests different "convenience yields" (Krishnamurthy and Vissing-Jorgensen, 2012) embedded in repos and it can lead to passthrough inefficiency of monetary policies (Duffie and Krishnamurthy, 2016a). The third (seasonal) pattern coincides with regulatory reporting periods. However, how exactly regulations affect repo rates is an open question, which we analyze in this paper.

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

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

3.2. CCP investments

Our analysis uses daily investments from EMIR-regulated clearing infrastructures as reported to the Bank of England between November 2013 and December 2017. Although our quantities are representative of the entire UK CCP infrastructure, confidentiality reasons prevent us from disclosing the clearing houses in our analysis. Nor are we able to divulge whether their investment activities stem merely from some or rather from all of their clearing services. What should be stressed, though, is that the compliance of the prudential regulation is the main concern guiding CCPs investments.

The data contain the reverse repo and bond purchase volumes that the supervised clearing houses settle every day to comply with the EMIR rule (see Section 2.1). These volumes are split by the collateral's country of origin. Although they are very granular, these reports do not distinguish between tenors.

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

The Levin et al. (2002) test rejects a unit root for CCPs' reverse repo investments, although we find that repo investments with one particular country's collateral are only weakly stationary. A removal of this country leads to rejecting of a unit-root at the 1% significance level. On the other hand, a unit-root in CCPs' bond investments cannot be rejected, likely due to some discrete jumps in investment volumes. We do appropriate robustness checks in Section 6.3 to verify that inclusion of this country and the bond investments control variable does not lead to spurious correlations in our results. We find that, if anything, inclusion works against our results.

3.3. Other data

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

The CIP basis is calculated as

$$CIP_{c,m,t} = r^{USD}_{t,t+m} - r^{ccy(c)}_{t,t+m} + \frac{252}{m}\left(f^{USD,ccy(c)}_{t,t+m} - s^{USD,ccy(c)}_{t}\right), \tag{1}$$

where t denotes the day and c denotes the (collateral) country of the panel cross-section. Variable m denotes the tenor of the repo segment in days (i.e., either 1 or 5), whereas $ccy(c)$ denotes the currency (i.e., either EUR or GBP) in which repos with collateral of country c are quoted. Variable r denotes the LIBOR interest rate (in logs), which were downloaded from the Federal Reserve Economic Data (FRED) website. Variables s and f denote the spot and forward FX rates (in logs) between USD and $ccy(c)$, respectively, given in units of $ccy(c)$ per USD. The FX rates were downloaded from Bloomberg.

We include the CIP basis as a control because interest rates and FX markets are closely interrelated. For banks and their customers, FX rates determine the most convenient sources of cross-border short-term funding and lending. FX rates also influence collateral management that can be crucial for covering short positions and preventing settlement failures. For instance, a bank facing a margin call might find it more worthwhile to execute a carry-trade, to lend in the foreign currency's repo market to obtain collateral, and to deliver said collateral to satisfy the margin call rather than to simply deliver domestic collateral already in its possession. Hence, FX rates influence which collateral is cheapest-to-deliver and therefore affect repo demand and supply. On the other hand, repo rates can affect FX rates. For instance, 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). 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).

Furthermore, we control for overall market volatility and margin procyclicality by including the VSTOXX measuring the EURO STOXX 50 implied volatility index.[22] Being an important determinant of how much margin must be deposited at CCPs for a given trade, volatility can influence how much cash CCPs must invest in reverse repos and government bonds. As margin requirements in the European interbank repo market are recalculated by looking at past volatility or are pre-established (e.g., Mancini et al., 2016; Nyborg, 2016), we control for this variable with a lag of one day.

Finally, we also control for the ECB's PSPP as it constitutes an alternative explanation (i.e., QE effects) for the repo rate patterns shown in Fig. 1 (e.g., Pelizzon et al., 2018; Arrata et al., 2020). To capture the size of PSPP operations,[23] we compute the percentage share of a outstanding debt that has been purchased by the ECB through PSPP, i.e.,

$$PSPP_{c,t} = \frac{Purchases_{c,t}}{Outstanding_{c,t}} \cdot 100, \tag{2}$$

where $Purchases_{c,t}$ denotes the cumulative PSPP purchases of country c's government debt until day t, and $Outstanding_{c,t}$ denotes that country's total outstanding debt[24] eligible for PSPP purchases. To construct $Purchases_{c,t}$, we start out with the monthly breakdown of PSPP purchases.[25] Using the weekly time series of "Securities held for monetary policy purposes" contained in the ECB's weekly financial statements, we interpolate $Purchases_{c,t}$ to weekly frequency.[26] The data source for weekly values of $Outstanding_{c,t}$ is the ECB's Eligible Assets database.[27] Finally, we compute weekly values of $PSPP_{c,t}$ and interpolate it linearly to daily frequency. As this variable is clearly not stationary, we use the day-to-day change $\Delta PSPP_{c,t}$ in the regressions.

4. Supply effects

4.1. Methods

The supply hypothesis puts forward that the regulatory-driven supply of repos (demand of collateral) by clearing houses decreases short-term rates. To test it, we use a standard panel regression setup. In Eq. (3), we outline the baseline regression equation used and adapted in subsequent sections:

$$\begin{aligned} Rate_{c,m,t} &= \alpha \cdot Rate_{c,m,t-1} + \gamma \cdot Orderflow_{c,m,t} \\ &\quad + \lambda \cdot Reverse_{c,t} + \mu_{c,m} + \boldsymbol{\beta}^T \boldsymbol{X}_{c,m,t} + \epsilon_{c,m,t}. \end{aligned} \tag{3}$$

The response variable $Rate_{c,m,t}$ denotes the spread between volume-weighted average interbank repo rates and the central bank deposit rate. The c (collateral country) and m (tenor) indices denote the cross-section of the panel, while $\mu_{c,m}$ denotes the standard fixed-effects dummies, one for every market segment.

We add the first lag of the dependent variable to control for any persistence in repo rates.[28] To account for en-

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

[23] Because of the self-imposed limits of the purchase programme, the ECB ran out of government bonds and also bought sub-sovereign and agency bonds, especially towards the end of our sample period. This is why this PSPP data may not be a very accurate control variable. Like in Arrata et al. (2020), accessing the ECB's proprietary data from PSPP purchases would solve this issue. On the other hand, our panel setting is quite similar to theirs and we obtain an effect that is both sizeable and consistent with their (causal) analysis. Hence, we are confident that our setting appropriately controls for PSPP effects.

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

[25] https://www.ecb.europa.eu/mopo/implement/app/html/index.en.html#pspp.

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

[27] https://www.ecb.europa.eu/paym/coll/assets/html/list-MID.en.html, although one would have had to download the data regularly since 2015. We are grateful for the ECB's assistance.

[28] Including lagged values of the dependent variable might introduce Nickell's (1981) bias. However, this is typically the case for panel regres-

dogenous demand and supply within the interbank market, we add interbank order flow as an explanatory variable. When repo rates are regressed on it, the estimated coefficient γ captures the order flow price impact within the interbank repo market.

The $Reverse_{c,t}$ variable contains the aggregate and standardized CCP reverse repo investment volume. The coefficient λ is the coefficient of main interest, as it captures the impact of CCP reverse repo investments in the OTC market on interbank repo rates. It is worth stressing that $Reverse_{c,t}$ can be interpreted as the order flow stemming from the CCPs cash lending in the OTC segment. Hence, we occasionally refer to λ as the price impact of the CCP reverse repo investments. We do so, although the CCPs trade OTC while the interbank market is based on centrally cleared electronic limit order books. Thus, it is important to remember that λ captures spillover effects from the OTC (bilateral) segment to interbank (centrally cleared) segment of the repo market. As discussed in Section 2.1, the CCP repo investment can be regarded as exogenous to the interbank repo market, as it is (a) driven by regulation, (b) determined by the amount of cash accumulated on CCPs' margin accounts, and (c) conducted in the OTC segment, while we analyze the impact on the interbank market.

The $\boldsymbol{X}_{c,m,t}$ vector contains our control variables:

$$\boldsymbol{X}_{c,m,t} = \left[Bonds_{c,t} \quad CIP_{c,m,t} \quad VSTOXX_{t-1} \quad \Delta PSPP_{c,t} \right]^{\top}. \quad (4)$$

As explained in Section 3.3, we control for FX dynamics (CIP basis), margin procyclicality (volatility), and QE (ECB's PSPP). We add CCPs' aggregate and standardized outright government bonds purchases as they can indirectly lower repo rates through "specialness," that is, collateral becomes scarce (Duffie, 1996). Hence, if $Reverse_{c,t}$ and $Bonds_{c,t}$ are correlated, excluding $Bonds_{c,t}$ from the regression would lead to an omitted variable bias in the coefficient λ.

To be conservative, we exclude the last day of each quarter from the regression to eliminate possible problems stemming from extreme seasonalities (in repo volume and rates, as well as CIP basis) and (unlikely) endogeneity (see discussion in Section 3.3). This also excludes or reduces confounding factors apart from leverage ratio reporting that might change a bank's repo trading behavior during these days (Bank for International Settlements, 2017). It is worth stressing that excluding the very last days at quarter-ends does not qualitatively change our main results and does not weaken our DiD identification strategy (see Section 5) because all repo tenors under scrutiny are equally affected during these days.

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

sions with an arbitrarily large cross-section but only a few time periods. As the number of time periods grows, the bias approaches zero. Given that our data feature a long time-series of 1065 business days and only 21 cross-sectional segments, we believe that our results do not suffer from this bias.

Table 2
Supply effects on repo rates.
The table reports the results of Eq. (3) that regresses *Rate*, defined as the spread between volume-weighted average interbank repo rates and the central bank rate, on the aggregate and standardized CCP reverse repo investment volume (*Reverse*). We control for the interbank repo order flow (*Orderflow*), CCPs' outright purchases of government bonds (*Bonds*), the covered interest rate basis between the repo currency and USD (*CIP*), lagged market expectations of volatility (*VSTOXX*), the share of a country's QE-eligible debt bought and held by the ECB (*PSPP*), and lagged repo rates. The cross-sectional segments are given by the combination of collateral country *c* and tenor *m*. The sample covers the period from November 4, 2013 to December 29, 2017. We report robust standard errors clustered by segment and quarter in parentheses. *, **, and *** denote significance at the 1%, 5%, and 10% confidence levels, respectively.

	$Rate_{c,m,t}$		
	(1)	(2)	(3)
$Reverse_{c,t}$	−4.864***	−4.712***	−1.559**
	(1.393)	(1.374)	(0.642)
$Orderflow_{c,m,t}$	0.343***	0.344***	0.279***
	(0.075)	(0.074)	(0.034)
$Bonds_{c,t}$		0.282	−0.129
		(0.885)	(0.345)
$CIP_{c,m,t}$			161.077***
			(55.401)
$VSTOXX_{t-1}$			0.128***
			(0.024)
$\Delta PSPP_{c,t}$			−29.389***
			(6.063)
$Rate_{c,m,t-1}$	0.485***	0.485***	0.767***
	(0.057)	(0.057)	(0.024)
Fixed effects	Segment	Segment	Segment
Adjusted R^2	0.478	0.478	0.669
Observations	13,212	13,212	12,727

4.2. Results

Table 2 shows the main findings. Two considerations arise: First, the estimates of the price impact of CCP reverse repo investments are significantly negative, providing support for the supply hypothesis. Every standard deviation increase in reverse repo investments lowers interbank repo rates from the central bank deposit rate by 4.864 bps. The estimated supply impact from CCP reverse repos drops to 1.559 bps, but remains significant after adding all control variables.

Second, all estimated coefficients of the control variables exhibit the expected signs, but they are not always statistically significant. Specifically, the estimates of the price impact of the interbank order flow is positive and significant, as postulated by microstructure theories. CCPs' bond purchases do not significantly affect the repo rates, suggesting that specialness has only an indirect effect in the regulatory transmission mechanism. On the other hand, the significance of the CIP estimate confirms the important connection between short-term interest rates and FX rates. Also, the positive coefficient of the volatility variable points to the tendency of funding cost to increase in stressed market conditions, inducing some margin procyclicality. In line with Arrata et al. (2020), PSPP pushes down repo rates.

Our results are economically significant. For confidentiality reasons, we cannot reveal the real effect of CCPs' reverse repo activity on repo rate, so instead we report its effect on the average repo rate daily variation (i.e., daily standard deviation). We do so by multiplying the reverse repo coefficient, -4.864 bps, from the baseline specification (column 1) by the average standard deviation of the reverse repo variable, 0.238, and then by dividing this product by the average daily standard deviation of the repo rate, 26 bps. This calculation suggests that about 1.158 bps or 4.5% of the daily repo rate variation can be attributed to the daily variation in the CCPs' reverse repo investments. This metric tends to underestimate the economic significance and it should be seen as a conservative estimate.[29] Nonetheless, this effect appears significant considering the sheer size of this market and comparing it to other money market interest rate dispersions [e.g., see Duffie and Krishnamurthy, 2016b for the US]. Using the full regression specification (column 3) with the lower reverse repo coefficient of -1.559 bps, we arrive at 0.371 bps or 1.4% of daily repo rate variation. For comparison, we repeat this computation for $\Delta PSPP_{c,t}$ to assess the impact of QE. We find that about 0.923 bps or 3.6% of the daily repo rate variation can be attributed to the implementation of PSPP. Despite the above-mentioned limitations of the PSPP data, we conclude that the impact of CCPs' reverse repo on the average daily repo rate variation is in the same ballpark as the one of PSPP, which is economically significant.

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

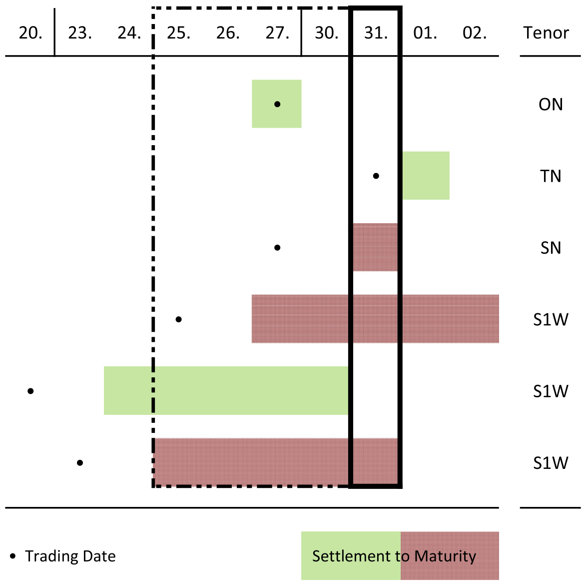

Fig. 4. Balance sheet impact around reporting days.
The figure presents different repo contracts settled around a balance sheet reporting day. Each column corresponds to a business day, with the thick bordered column representing the reporting day. Each row corresponds to a repo trade. The bars highlight those days on which each trade ends up on the balance sheet. The darker shading indicates that a repo shows up on the balance sheet during the reporting day. All one-week repos settled during the four days before the reporting day end up on the balance sheet on the reporting day, unlike the one-day repos. Note that the trading day is irrelevant. Hence, our t index always denotes settlement dates.

5. Demand effects

5.1. Methods

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

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

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

Therefore, we test whether repo demand falls by checking whether the negative price impact of CCPs' reverse repo investments becomes stronger (i.e., the coefficient λ in (3)). We employ a DiD design to causally attribute these changes to the leverage ratio regulation. Whether a repo position ends up on the balance sheet and worsens a bank's leverage ratio depends on its tenor and on the leverage ratio disclosure schedule. This has been documented by Du et al. (2018) for FX derivatives. They show that CIP violations increase when leverage ratios must be disclosed to authorities. However, as most European authorities only ask for a snapshot of the balance sheet on the last day of the quarter, only contracts that have not yet matured will be affected by leverage ratio regulations. For example, a one-week forward position traded on March 1 will not affect the balance sheet on March 31, when the leverage ratio must be reported. However, a one-month forward position traded on the same day will end up on the balance sheet and affect the bank's leverage ratio. Therefore, CIP violations involving one-month forwards will be larger.

Analyzing one-day and one-week tenors enables us to exploit the same differences in the repo market (see Fig. 4).

[29] This method understates the price impact if CCPs smooth the daily variation of their reverse repos. Since we are not allowed to disclose further information including the average CCPs investment per market segment, we cannot offer a better economic proxy.

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 the leverage ratio regulation, whereas one-day repos are not. If repo demand is affected by leverage ratio regulations, we expect the price impact of CCP reverse repo investments on one-week repos to become more negative during those four days. In contrast, the price impact on one-day repos is not expected to change during this time period. Hence, we compute the difference in price impacts between one-day and one-week repos and test whether it changes during the last four days of the quarter. A change in this difference should be caused by falling borrowing demand due to leverage ratio regulation.

We introduce two additional dummy variables into Eq. (3) to estimate this change of differences. Variable $1W_m$ equals 1 if the tenor m is spot-1-week (S1W, 5 business days), and 0 otherwise. Similarly, $BeforeEoQ_t$ equals 1 if day t is 1–4 days before the end of a quarter, and 0 otherwise. To obtain the DiD estimator, we interact these dummies with CCP reverse repo investments $Reverse_{c,t}$, as follows:

$$\begin{aligned} Rate_{c,m,t} = {} & \alpha \cdot Rate_{c,m,t-1} + \gamma \cdot Orderflow_{c,m,t} \\ & + \lambda_1 \cdot Reverse_{c,t} + \lambda_2 \cdot 1W_m \cdot Reverse_{c,t} \\ & + \lambda_3 \cdot BeforeEoQ_t \cdot Reverse_{c,t} \\ & + \lambda_4 \cdot 1W_m \cdot BeforeEoQ_t \cdot Reverse_{c,t} + \mu_{c,m} \\ & + \boldsymbol{\beta}^T \boldsymbol{X}_{c,m,t} + \eta \cdot BeforeEoQ_t + \epsilon_{c,m,t} \end{aligned} \tag{5}$$

In Eq. (5), 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 DiD estimator and captures the additional impact on one-week repos before the end of the quarter. We also add the uninteracted $BeforeEoQ_t$ term to account for overall differences in the level of $Rate_{c,m,t}$ before the end of the quarter. Note that we do not explicitly add the uninteracted $1W_m$ term because it is absorbed into the fixed effects $\mu_{c,m}$.

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

Table 3
Demand effects on repo rates.
This table reports the results of Eq. (5), where the *Rate*, defined as the spread between volume-weighted average interbank repo rates and the central bank rate, is regressed on the CCP reverse repo investment (*Reverse*), time and tenor dummies (*BeforeEoQ* and $1W$), and their interactions with *Reverse* implementing the difference-in-differences estimator. We control for the interbank repo order flow (*Orderflow*), CCPs' outright purchases of government bonds (*Bonds*), the covered interest rate basis between the repo currency and USD (*CIP*), lagged market expectations of volatility (*VSTOXX*), the share of a country's QE-eligible debt bought and held by the ECB (*PSPP*), and lagged repo rates. The cross-sectional segments are given by the combination of collateral country c and tenor m. The sample covers the period from November 4, 2013 to December 29, 2017. We report robust standard errors clustered by segment and quarter in parentheses. *, **, and *** denote significance at the 1%, 5%, and 10% confidence levels, respectively.

	$Rate_{c,m,t}$		
	(1)	(2)	(3)
$Reverse_{c,t}$	−3.450***	−3.385***	−0.808**
	(1.198)	(1.190)	(0.426)
$Reverse_{c,t} \cdot 1W_m$	−16.154***	−16.105***	−9.068***
	(4.988)	(4.960)	(3.255)
$Reverse_{c,t} \cdot BeforeEoQ_t$	0.710	0.714	0.181
	(0.865)	(0.865)	(0.541)
$Reverse_{c,t} \cdot BeforeEoQ_t \cdot 1W_m$	−31.249**	−31.224**	−30.769**
	(14.536)	(14.546)	(14.586)
$BeforeEoQ_t$	−2.513	−2.508	−2.798
	(2.968)	(2.967)	(1.825)
$BeforeEoQ_t \cdot 1W_m$	−110.713**	−110.637**	−106.853**
	(51.644)	(51.678)	(50.835)
$Orderflow_{c,m,t}$	0.355***	0.355***	0.282***
	(0.076)	(0.076)	(0.034)
$Bonds_{c,t}$		0.129	−0.223
		(0.891)	(0.363)
$CIP_{c,m,t}$			124.278***
			(31.440)
$VSTOXX_{t-1}$			0.125***
			(0.023)
$\Delta PSPP_{c,t}$			−34.299***
			(5.748)
$Rate_{c,m,t-1}$	0.478***	0.478***	0.755***
	(0.056)	(0.056)	(0.025)
Fixed effects	Segment	Segment	Segment
Adjusted R^2	0.497	0.497	0.680
Observations	13,212	13,212	12,727

5.2. Results

Table 3 shows the estimates from the DiD regression Eq. (5), which isolates the causal effect of leverage ratio reporting on repo rates. During the four days before the last day of the quarter (when leverage ratios must be calculated and reported), the difference between the price impacts of one-day and one-week repos changes significantly. While the former additional price impact is statistically insignificant, the latter suffers from an additional staggering price impact of -31.249 bps per standard deviation. Adding control variables does not change the size or the significance of that estimate. Given that repo supply is not affected by leverage ratio concerns, a stronger price impact should be mostly caused by decreasing repo demand. More specifically, the slope of the demand curve must become more negative, which is identified by this additional price impact. On the other hand, the inward shift of the demand curve is captured by the coefficient of $BeforeEoQ_t \cdot 1W_m$, which is also significantly negative.[30] Overall, our results suggest that the demand falls for repos that end up on the balance sheet during quarter-ends. In contrast, the demand for repos not affected by the leverage ratio regulation remains unchanged.

6. Additional tests

We have so far uncovered the effect of the EMIR and Basel III on short-term rates. Next, we explore the transmission mechanism. In particular, we explore whether the EMIR and Basel III regulations expand repo rate dispersion and whether they affect interbank borrowing and lending of individual banks that act as CCPs' investment counterparties in the OTC segment.

6.1. Repo spreads and dispersion

6.1.1. Methods

One of the takeaways from Fig. 1 is the increase in the repo rate dispersion across the different European countries. Cross-sectionally, repos secured by higher quality collateral (e.g., German) exhibits much lower rates than those secured by less safe ones (e.g., Italian) and these high-low yield spreads have increased, especially after 2016.[31] This could be consistent with an uneven impact of regulation induced by convenience yields and collateral scarcity. The basic intuition is that near-money assets provide safety and liquidity benefits to their holders. This gives rise to a convenience yield, which increases with asset scarcity (Krishnamurthy and Vissing-Jorgensen, 2012). The differences in convenience yields have been found to explain cross-sectional and temporal variations in money market instruments (e.g., Bartolini et al., 2011; Ballensiefen and Ranaldo, 2019).

In compliance with the prudential regulation mandating CCPs to hold only high-quality assets, we expect that CCPs primarily invest in high-quality collateral. Thus, CCP reverse repos decrease repo rates secured by high-quality assets rather than those of low-quality collateral. The overall impact would be that more CCP reverse repos are associated with larger high-to-low repo spreads, pointing to a relative increase in convenience yields and aggravated scarcity of high-quality assets.

An alternative hypothesis is that CCPs undertake a sort of carry trade, opportunistically investing in high-yield repos and shorting low-yield ones. This hypothesis predicts narrower spreads are associated with CCPs reverse repos as lending (borrowing) at the high (low) rate lowers (raises) the upper (lower) component of the spread, thereby converging them.

The repo rate dispersion could be exacerbated by limited intermediation (or trading) due to balance sheet constraints. In a frictionless market, a bank could exploit such a dispersion by borrowing at a low rate and, simultaneously, lending at a high rate in a sort of arbitrage trading (Bech and Klee, 2011). However, such a trading strategy would give rise to a regulatory cost as it would expand the bank's balance sheet (such repo positions cannot be netted out as they involve different collateral; see also the discussion in Section 2.2). Therefore, these regulatory-driven costs can increase segmentation in repo markets, creating systematic rate dispersion that magnifies during the leverage ratio reporting dates.

We measure the repo (yield) spread or repo rate dispersion as:

$$Spread_{q,b,m,t} = Rate_{q,m,t} - Rate_{b,m,t}. \tag{6}$$

Analogous to Eq. (3), $Rate_{\cdot,m,t}$ denotes the differential between the volume-weighted interbank repo rate and the central bank deposit rate for tenor m at day t, and it is defined for a "quote" country q and a "base" country b. We fix the base b to the country exhibiting the lowest average repo rate, which ensures that the spread measure is positive. Consistent with the safe asset paradigm, the repo with the lowest rate provides the largest convenience yield. In what follows, we drop the index b since it is fixed. We next run the following panel regression, whereby the combination of q and m constitute the cross-section:[32]

$$\begin{aligned} Spread_{q,m,t} = {} & \alpha \cdot Spread_{q,m,t-1} + \gamma_1 \cdot Orderflow_{q,t} \\ & + \gamma_2 \cdot Orderflow_{b,t} + \lambda_1 \cdot Reverse_{q,t} \\ & + \lambda_2 \cdot Reverse_{b,t} + \boldsymbol{\beta}^T \boldsymbol{X}_{q,m,t} + \mu_{q,m} + \epsilon_{q,m,t}, \end{aligned} \tag{7}$$

where the vector of control variables is defined as:

$$\begin{aligned} & \boldsymbol{X}_{q,m,t} \\ & = \left[Bonds_{q,t} \quad Bonds_{b,t} \quad CIP_{q,m,t} \quad VSTOXX_{t-1} \quad \Delta PSPP_{q,t} \quad \Delta PSPP_{b,t} \right]^{\top}. \end{aligned} \tag{8}$$

We exclude sterling repos from these regressions to ensure that the dispersion is not driven by currency-specific factors. The coefficients λ_1 and λ_2 capture the impact of CCP reverse repo investments on the repo rate spread between country q and the base country b. Given that the supply hypothesis implies a negative rate impact from CCPs' reverse repos, λ_1 (λ_2) can be negative (positive). The net effect on the high-to-low spread depends upon the investment policy of CCPs (prudential policy vs. opportunistic strategies), as well as the price impact impounded by reverse repo volumes. Hence, the net effect is not necessarily directly discernible from estimates of λ_1 and λ_2 as they must be weighted by CCPs investments into quote and base countries, which we must not disclose.

In addition to the separate base and quote effects, we estimate an overall impact. Specifically, we take the sum over all reverse repo investments, that is, $TotalReverse_t =$

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

[31] Note that the leverage ratio cannot drive such a repo rate dispersion as it is an unweighted risk-measure and hence does not differentiate between repos with different collateral.

[32] Eq. (7) can be obtained by taking the definition of $Spread_{q,b,m,t}$, substituting in Eq. (3) twice (for base- and quote-country respectively) and collecting terms.

$\sum_c Reverse_{c,t}$, and regress spreads on total reverse repo investments, as follows:

$$\begin{aligned} Spread_{q,m,t} =& \alpha \cdot Spread_{q,m,t-1} + \gamma_1 \cdot Orderflow_{q,t} \\ &+ \gamma_2 \cdot Orderflow_{b,t} + \lambda \cdot TotalReverse_t \\ &+ \boldsymbol{\beta}^T \boldsymbol{X}_{q,m,t} + \mu_{q,m} + \epsilon_{q,m,t}. \end{aligned} \tag{9}$$

Here the interpretation of λ is unambiguous. If λ is positive, then CCPs' reverse repo investments increase the repo spread. Finally, we repeat the DiD regression (5) for spreads (instead of rates):

$$\begin{aligned} Spread_{q,m,t} =& \alpha \cdot Spread_{q,m,t-1} + \gamma_1 \cdot Orderflow_{q,t} \\ &+ \gamma_2 \cdot Orderflow_{b,t} + \lambda_1 \cdot TotalReverse_t \\ &+ \lambda_2 \cdot 1W_m \cdot TotalReverse_t \\ &+ \lambda_3 \cdot BeforeEoQ_t \cdot TotalReverse_t \\ &+ \lambda_4 \cdot 1W_m \cdot BeforeEoQ_t \cdot TotalReverse_t + \mu_{c,m} \\ &+ \boldsymbol{\beta}^T \boldsymbol{X}_{c,m,t} + \eta \cdot BeforeEoQ_t + \epsilon_{c,m,t} \end{aligned} \tag{10}$$

If the leverage ratio regulation increases rates dispersion in the euro repo market, then we expect λ_4 to be positive.

6.1.2. Results

Table 4 delivers three main results. First, column 1 indicates that CCPs predominantly invest in the safest (i.e., low-rate) base country, thereby increasing the spread by about 6.876 bps per standard deviation of reverse repo investments. Conversely, investments in the more lucrative (i.e., high-rate) quote country have no significant effect. This corroborates our main hypothesis, that is, the main aim of CCPs is to comply with the prudential regulation and CCPs mostly care about collateral safety rather than undertaking opportunistic positions, which would imply a significantly negative coefficient on the quote country. Furthermore, it provides empirical support for the safe asset hypothesis, that is, the regulatory-driven demand for high-quality collateral from the clearing infrastructure increases the convenience yield of these highest rated assets.

Second, the results in columns 2 and 3 show that CCPs' reverse repo investments due to EMIR widen repo rate dispersion. For instance, a one standard deviation increase in total reverse repo investments, regardless of country, increases rate dispersion by 3.475 bps.

Third, the results in columns 4 and 5 in Table 4 (i.e., the DiD setting as in Eq. (10)), suggest that repos that end up on the banks' balance sheet during reporting days exhibit an additional increase in rate dispersion of 21.394 bps per standard deviation of reverse repo investments. This is consistent with the balance sheet constraints hypothesis. The drop in the demand due to the leverage ratio regulation increases repo spreads and exacerbates the impact of repo supply.

6.2. Behavior of CCP investment counterparties

In this section, we investigate the transmission mechanism of regulations through the lens of the banks' individual behavior. We do so by analyzing how individual banks borrow and lend in the interbank market, and whether their behavior is different when they act as CCPs' investment counterparties in the OTC repo segment.

Entering a bilateral repo with a CCP has three main effects for a bank: a cash surplus, a shortage of HQLA assets, and an expansion of the balance sheet. Given the associated inventory and regulatory costs (see the discussion in Section 2.2), banks that trade with the CCP in the OTC repo market have an incentive to offset any cash and asset imbalances in the interbank market. Thus, two testable hypotheses arise: First, the banks that act as the CCPs investment counterparties are expected to lend more in the interbank market. Second, these banks should also reduce their provision of market liquidity in the interbank market as a result of the balance sheet expansion and the associated costs. Note that any bank positions held in the OTC segment cannot be netted against positions held in the interbank segment.

6.2.1. Methods

To analyze individual bank' behaviors in the interbank market, we consider their propensity to lend or borrow cash, and to provide or consume liquidity.[33] As standard in market microstructure, the submission of market and limit orders defines the consumption and provision of market liquidity, respectively. Specifically, we divide a bank's daily gross trading volume into four shares: (1) borrowing cash with market orders ("aggressive" borrowing consuming liquidity); (2) borrowing with limit orders ("non-aggressive" borrowing supplying liquidity); (3) lending with market orders (aggressive lending); and (4) lending with limit orders (non-aggressive lending). Let k denote bank k, and let the pair (t, j) denote the jth transaction on day t. The propensity of bank k to borrow (lend) cash consuming (providing) market liquidity on day t is given by $MarketBorrow_{k,t}$ ($LimitLend_{k,t}$) and defined as follows:

$$\begin{aligned} MarketBorrow_{k,t} &= \frac{\sum_j \mathbf{1}\{Borrower_{t,j}=k \wedge Aggressor_{t,j}=k\} \cdot Volume_{t,j}}{\sum_j Volume_{t,j}} \\ LimitLend_{k,t} &= \frac{\sum_j \mathbf{1}\{Lender_{t,j}=k \wedge Aggressor_{t,j}\neq k\} \cdot Volume_{t,j}}{\sum_j Volume_{t,j}}, \end{aligned} \tag{11}$$

where $Volume_{t,j}$ denotes the cash amount and $Borrower_{t,j}$ ($Lender_{t,j}$) denotes the identity of the borrower (lender) of transaction (t, j). Finally, $Aggressor_{t,j}$ denotes the identity of the bank initiating the trade with a market order. The two other shares, $MarketLend_{k,t}$ and $LimitBorrow_{k,t}$ are defined analogously. Note that these four shares sum up to one by definition since for each (t, j) either the lender or the borrower is equal to the aggressor.

Using the same sample period as before, we obtain panel regressions whose cross-sections consist of individual banks (rather than collateral countries and tenors, as before). To determine how banks react to CCPs' reverse repos, we regress each share $Y_{k,t}$ on the total volume of CCPs'

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

Table 4
Effects on repo rate dispersion.
The table reports the regression results of Eqs. (7), (9), and (10), where the *Spread* denotes the difference in repo rates between a "quote" (q) and a "base" (b) country with the same tenor (m). The cross-sectional segments are therefore given by combination of tenor, quote- and base-country, whereby we fix the latter to the country that exhibited the lowest repo rates on average. The *Spread* is regressed either on the CCP reverse repo investment (*Reverse*), or on overall CCP reverse repo investments regardless of collateral country (*TotalReverse*). As in the regression of Table 3, we include tenor and time dummies, their interaction with *Reverse*, and a number of control variables. The sample covers the period from November 4, 2013 to December 29, 2017. We report robust standard errors clustered by segment and quarter in parentheses. *, **, and *** denote significance at the 1%, 5%, and 10% confidence levels, respectively.

	$Spread_{q,m,t}$				
	(1)	(2)	(3)	(4)	(5)
$Reverse_{b,t}$	6.876***				
	(0.582)				
$Reverse_{q,t}$	1.943				
	(1.551)				
$TotalReverse_t$		4.570***	3.475***	4.781***	3.610***
		(0.378)	(0.354)	(0.324)	(0.214)
$TotalReverse_t \cdot 1W_m$				−2.314***	−1.910***
				(0.806)	(0.629)
$TotalReverse_t \cdot BeforeEoQ_t$				−2.048*	−1.984**
				(1.071)	(0.808)
$TotalReverse_t \cdot BeforeEoQ_t \cdot 1W_m$				21.473***	21.394***
				(7.946)	(8.265)
$BeforeEoQ_t$				4.041***	2.981***
				(0.885)	(0.680)
$BeforeEoQ_t \cdot 1W_m$				4.446	4.350
				(2.771)	(2.497)
$Orderflow_{b,t}$	−0.081***	−0.057**	−0.079***	−0.057**	−0.076***
	(0.025)	(0.023)	(0.020)	(0.023)	(0.019)
$Orderflow_{q,t}$	0.158***	0.142***	0.118***	0.146***	0.121***
	(0.027)	(0.025)	(0.021)	(0.024)	(0.021)
$Bonds_{b,t}$	−2.346***	−0.516	−0.541*	−0.656	−0.524*
	(0.318)	(0.399)	(0.308)	(0.364)	(0.307)
$Bonds_{q,t}$	0.357	−0.260	0.217	−0.376	0.073
	(0.395)	(0.299)	(0.256)	(0.286)	(0.235)
$CIP_{EUR,m,t}$			−100.553***		−44.752***
			(38.340)		(14.339)
$VSTOXX_{t-1}$			−0.080***		−0.086***
			(0.019)		(0.019)
$\Delta PSPP_{b,t}$			−1.979		2.444
			(3.262)		(2.236)
$\Delta PSPP_{q,t}$			−6.335		−5.542
			(4.805)		(4.416)
$Spread_{q,m,t-1}$	0.416***	0.394***	0.520***	0.388***	0.512***
	(0.025)	(0.023)	(0.028)	(0.023)	(0.029)
Fixed effects	Segment	Segment	Segment	Segment	Segment
Adjusted R^2	0.360	0.378	0.401	0.399	0.420
Observations	14,438	14,438	13,885	14,438	13,885

reverse repo investments, $TotalReverse_t$, the lagged dependent variable, bank and month fixed effects, as well as a set of controls.

The key innovation in these regressions is to capture the behavior of banks that trade with the CCPs in the OTC repo segment. We do so by constructing a dummy variable $Counterparty_k$, which equals one for banks that were the investment counterparties of the CCPs in our sample throughout our sample period. More formally, the regressions are defined as follows:

$$Y_{k,t} = \mu_{1,k} + \mu_{2,month(t)} + \alpha \cdot Y_{k,t-1} + \boldsymbol{\beta}^T \mathbf{X}_t + \lambda_1 \cdot TotalReverse_t + \lambda_2 \cdot Counterparty_k \cdot TotalReverse_t + \epsilon_{k,t}, \tag{12}$$

where the coefficients $\mu_{1,k}$ and $\mu_{2,month(t)}$ indicate the market participant and month fixed effects, respectively. The coefficient λ_2 of the interaction term between the $Reverse_t$ and the $Counterparty_k$ is the main variable of interest.[34]

A significant positive λ_2 for $Y_{k,t} = MarketLend_{k,t}$ and for $Y_{k,t} = LimitLend_{k,t}$ would support that the CCPs' investment counterparties tend to lend more in the interbank market. Similarly, a significant negative λ_2 for $Y_{k,t} = MarketBorrow_{k,t}$ and for $Y_{k,t} = LimitBorrow_{k,t}$ would support that the CCPs' counterparties in the OTC repo segment tend to borrow less. Finally, significantly negative λ_2 coefficients associated with $Y_{k,t} = LimitLend_{k,t}$ and $Y_{k,t} = LimitBorrow_{k,t}$ would be in line with a reduced provision of market liquidity by CCPs' counterparties.

[34] Reverse repos that each bank conducts with CCPs are not fully accessible so we cannot perform a panel regression at the bank or CCP level.

The set of controls X_t contains variables that may influence individual banks' trading behavior:

$$\boldsymbol{X}_t = [Bonds_t \;\; OrderShare_t \;\; \Delta Rate_t \;\; \log(Volume_t) \;\; EffectiveSpread_t \;\; CIP_t \times VSTOXX_{t-1}]^{\top}. \tag{13}$$

We include CIP_t and $VSTOXX_{t-1}$ that we also use as control variables in previous regressions. Note that here we fix the currency to the euro and the tenor to one day, and we therefore drop the c and m indices from $CIP_{c,m,t}$. In addition, we consider four market variables that can influence the trading behavior of individual banks. First, to capture overall market imbalances, $OrderShare_t$ is defined as the market order flow divided by gross trading volume. The main idea is that one-sided markets (i.e., $|OrderShare_t|$ is close to one) may affect order aggressiveness. Second, we add the daily repo rate change as a higher (lower) rate might discourage borrowing (lending). Third, (log) total trading volume captures overall activity in the market. Fourth, we estimate effective spreads, as transaction cost is an important dimension of market illiquidity influencing the propensity to trade and to provide liquidity.[35],[36]

6.2.2. Results

Table 5 provides the results. Three key findings stand out. First, the strongest result is obtained for aggressive lending. For every standard deviation increase in CCPs' reverse repo lending, banks borrowing from CCPs in the OTC segment (i.e., the banks that act as the investment counterparties of CCPs) lend 0.82% more in the interbank market relative to banks that did not borrow from a CCP. This supports the hypothesis that banks borrowing from CCPs tend to offload cash surpluses by lending aggressively to other banks in the interbank market.

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

Third, there is mixed evidence of diminished market liquidity provided by banks entering repos with CCPs in the OTC segment. Non-aggressive borrowing of CCP counterparties experiences a drop of 0.57% per standard deviation of CCP reverse repos relative to other banks. This is consistent with banks cutting back on intermediation in response to being leverage-constrained by repo borrowing positions obtained against the CCPs in the OTC segment and which cannot be netted with other positions.[37] On the other hand, the impact on non-aggressive lending is insignificant, perhaps because the diminished liquidity provision is offset by a larger pressure to lend in the interbank market.

6.3. Robustness tests

Our findings provide compelling evidence that the supply and demand regulatory effects hold true after controlling for QE effects proxied by PSPP volume. As discussed in Section 2), a potential concern is that QE affects the initial margin contributions of clearing members. More specifically, the increased excess liquidity and collateral scarcity originated from the PSPP program might induce clearing members to deposit more cash than necessary on margin accounts, thus, affecting the level of CCP investment in repo markets. In addition to the reasons already mentioned,[38] we do not find any empirical support for this mechanism. Specifically, the correlation between $\Delta PSPP_{i,t}$ and $\Delta Reverse_{i,t}$ is close to zero. Hence, it is very unlikely that QE drives the CCP repo investment policy.

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

As banks need to disclose both the leverage ratio and the LCR simultaneously, our results supporting the demand hypothesis might partially capture some LCR effects. Disentangling the LCR and leverage ratio effects is exceedingly difficult, and to our knowledge, has not been attempted before. However, it is worth stressing that our setup is especially well-suited to isolate the leverage ratio effects because the repo market under scrutiny almost exclusively features short-lived tenors below 30 days and tier 1 collateral. Nevertheless, some spillover effects could come from a specific window-dressing setting; for instance, a swap of low- for high-quality collateral performed with bilateral repo and reverse repo transactions, which also features longer-lived contracts for lower-quality collateral.[39] As the

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

[36] We repeat this analysis and include $\Delta PSPP_t$ as an additional control and we obtain an insignificant coefficient. We present the regression results without $\Delta PSPP_t$ because its inclusion only raises estimator variance without materially changing the results.

[37] Banks cannot net out their repo borrowing from CCPs because there is no multilateral netting in bilateral agreements and CCPs do not regularly lend. Hence, this applies to both the OTC and the centrally cleared market.

[38] CCPs discourage their members from depositing cash collateral by charging a spread on the overnight benchmark index. This spread makes any excess cash deposits by clearing members inefficient and unattractive. Furthermore, the CPMI-IOSCO Public Quantitative Disclosures by European CCPs show that the composition of collected margin is very stable quarter-by-quarter, with cash accounting for about 45%.

[39] Dealers in the bilateral segment might face exceptional demand for high-quality collateral and transmit the resulting specialness premium

Table 5
Effects on behavior of CCP investment counterparties.
The table reports regression results of Eq. (12). The four dependent variables denote the shares of individual banks' trading volume conducted using borrowing/lending and market/limit orders. These shares are regressed on the overall CCP reverse repo investment (*TotalReverse*), an interaction between *TotalReverse* and a dummy, *Counterparty*, indicating whether a bank is a counterparty for CCPs' investments in the OTC repo market. We control for CCPs' outright purchases of government bonds (*Bonds*), the interbank repo orderflow as a share of total turnover (*OrderShare*), the day-to-day change in average repo rates ($\Delta Rate$), the log of total turnover ($log(Volume)$), the effective bid-ask spread ($EffectiveSpread$), the covered interest rate basis between EUR and USD (*CIP*), lagged market expectations of volatility ($VSTOXX$), and the lagged dependent variable. The sample covers the period from November 4, 2013 to December 29, 2017. We report robust standard errors clustered by bank and month in parentheses. *, **, and *** denote significance at the 1%, 5%, and 10% confidence levels, respectively.

	$MarketBorrow_{k,t}$ (1)	$LimitBorrow_{k,t}$ (2)	$MarketLend_{k,t}$ (3)	$LimitLend_{k,t}$ (4)
$TotalReverse_t$	0.00135	0.00257*	−0.00428***	0.00045
	(0.00142)	(0.00155)	(0.00160)	(0.00139)
$TotalReverse_t \cdot Counterparty_k$	−0.00180	−0.00569***	0.00823***	−0.00049
	(0.00166)	(0.00185)	(0.00203)	(0.00174)
$Bonds_t$	−0.00164	0.00012	0.00072	0.00052
	(0.00136)	(0.00145)	(0.00166)	(0.00138)
$OrderShare_t$	0.13843***	−0.13693***	−0.14859***	0.17300***
	(0.00836)	(0.00941)	(0.00998)	(0.00895)
$\Delta Rate_t$	0.01969*	−0.00150	−0.00261	−0.01144
	(0.01059)	(0.01336)	(0.01474)	(0.01149)
$log(Volume_t)$	−0.00161	0.01249	−0.01037	−0.00371
	(0.01010)	(0.01148)	(0.01247)	(0.01133)
$EffectiveSpread_t$	−0.00003	−0.00014	−0.00016*	0.00026***
	(0.00008)	(0.00009)	(0.00009)	(0.00009)
CIP_t	0.21698**	−0.16037	−0.27757**	0.19254*
	(0.09655)	(0.09868)	(0.12070)	(0.10882)
$VSTOXX_{t-1}$	0.00019	−0.00073***	0.00023	0.00026
	(0.00024)	(0.00025)	(0.00027)	(0.00025)
$MarketBorrow_{k,t-1}$	0.34354***			
	(0.00969)			
$LimitBorrow_{k,t-1}$		0.47831***		
		(0.00998)		
$MarketLend_{k,t-1}$			0.45202***	
			(0.00986)	
$LimitLend_{k,t-1}$				0.35125***
				(0.01007)
Fixed effects	Bank & Month	Bank & Month	Bank & Month	Bank & Month
Adjusted R^2	0.129	0.237	0.213	0.135
Observations	69,481	69,481	69,481	69,481

LCR must be disclosed monthly, as a robustness test we replicate our analysis after removing all month-ends from the sample.[40] We find that the same significant results supporting the supply hypothesis and rate dispersion analysis. The results supporting the demand hypothesis should not be biased given the peculiarity of the window-dressing setting described above, but we cannot rule it out completely.

A further concern could be the inclusion in our sample of all repo transactions (i.e., general collateral as well as specific collateral). Firstly, CCPs might prefer to obtain high-quality collateral regardless of the exact identity (ISIN) of the collateral security and therefore prefer general collateral (GC) markets. Secondly, specific repo rates can become special due to exceptional demand and exhibit very low rates, especially since the PSPP is deemed to have increased collateral scarcity. To address this concern, we perform a sub-sampling analysis including only GC repos. We find consistent or even stronger results (e.g., in the case of the demand effects), suggesting the general validity of our analyses.

In Section 2.1, we discuss the exogeneity of CCPs reverse repo investments in regards to interbank repo rates. To provide additional evidence, we construct a bivariate VAR endogenizing aggregate CCPs reverse repo investments (i.e., $TotalReverse_t$ in Section 6.1) and market-wide (volume-weighted) average repo rates. We select the optimal number of lags to include by minimizing the Bayesian information criterion (BIC) and inspect estimates and their significance to test for reverse causality. The BIC indicates four lags as optimal, corresponding to four business days. We find that all coefficients, at any lag, that link current CCP reverse repo investments with past repo rates to be small and insignificant (even at the 20% significance level). On the other hand, half of the coefficients that link current repo rates with past CCP investments are negative (consistent with our hypotheses) and significant (between the 8% and 0.5% significance levels). In addition, we repeat the VAR analysis in first differences and find consistent results.

into the interbank market through their bond inventory. If this specific spillover effect arises at quarter-ends, then our demand effect might capture some of it.

[40] When we remove month-ends, we include the business weeks leading up to them. Also, note that the DiD analysis of the demand hypothesis cannot be reproduced without the week before the quarter end as it defines the treatment period.

Overall, we find no empirical support for reverse causality affecting our results.

Finally, we address concerns of spurious correlations in our results due to potential non-stationarity in some of our variables. Most importantly, we remove from the cross-section a single country whose CCP reverse repo investments are only weakly stationary. Our results remain virtually unchanged. In addition, we remove some control variables exhibiting strong persistence, namely, the $Bonds_{i,t}$ and $VSTOXX_{t-1}$ variables. We find that all estimates remain of the same signs and similar in magnitude and significance. Furthermore, and even though we take first differences, $\Delta PSPP_{i,t}$ still exhibits some persistence. Excluding it from the regression, as well as replacing it with the change in day-to-day change in Eurosystem excess liquidity, does not materially affect our results.[41] Our results also stay significant if we apply all of these changes at the same time. More in general, we find that our results remain equally strong or even become stronger (both in magnitude and significance) in each of these robustness checks.

7. Conclusion

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

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

Our analysis is relevant to policy makers as it highlights several unintended effects on short-term rates that are caused by some regulatory reforms. Compliance with these regulations strengthens cash supply and collateral demand. This results in larger dispersion and downward pressure on interbank rates, which impedes monetary policy effectiveness (Duffie and Krishnamurthy, 2016a).[42] This phenomenon has been attributed to various factors, including collateral scarcity due to central banks' extraordinary monetary policy instruments and market segmentation (Duffie et al., 2015). Our findings offer an alternative explanation and point to prudential regulations, which make CCPs new important market players and constrain the trading books and balance sheets of repo intermediaries.

Various remedies can be considered. First, regulators should consider the joint effects of existing and new regulations. For instance, more comprehensive inspection, as we propose in this paper, illuminates what the interaction between CCP compliance with EMIR rules and the Basel III leverage ratio regulation implies for short-term rates. Second, carefully (re-)designing some regulations might move us closer to the efficient frontier of market efficiency and financial stability (Duffie, 2018). For instance, the strong seasonalities around quarter ends might 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 repos and reverse repos and partially deter banks from window-dressing behavior. 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 nonfinancials 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.[43]

From a financial stability perspective, CCPs are systemically important financial institutions. In extraordinary circumstances CCPs might need to replenish their resources by liquidating the positions and margins of CCP members.[44] In this situation, CCPs would have to cut back on their reverse repo lending, or even become a repo borrower. Through the lens of our findings, short-term rates

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

42 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.

43 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.

44 Earlier layers of CCPs' default waterfall are initial margins of defaulting members, default fund contributions, and contributions to CCP capital (Cont, 2015).

would increase and banks would lend less in the interbank market, amplifying distressed market conditions.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jfineco.2021.04.016.

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