Collateral Cycles*

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Abstract

Using supervisory data from UK central counterparties (CCPs), our paper uncovers persistent collateral cycles in which cash goes back and forth from financial markets to CCPs. In the onward phase of the cycle, clearing members utilize repurchase agreements (repos) to provide cash to CCPs for meeting margin requirements. This pattern is procyclical, intensifying with market volatility and driving up repo rates. In the backward phase, CCPs return the cash to the financial markets via reverse repos and bond purchases, in compliance with regulation that requires CCPs to invest their cash holdings in safe assets. The cash given back by CCPs generates downward pressure on repo rates in a countercyclical manner.

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1 Introduction

Central counterparties (CCPs) reduce counterparty risk in securities and derivatives markets by the novation of trades; that is, by becoming a counterparty to both the buyers and sellers in each trade and requiring collateral (or margin) to cover the resultant exposures. CCPs have become a critical component of the financial system, since the 2008 Global Financial Crisis, as new regulation has sought to increase the collateralization of exposures in derivatives markets, the majority of which are now centrally cleared. Although this has led to an overall increase in collateral demand (ISDA, 2021), the implications of central clearing for the overall flow and distribution of collateral are still unclear.

Our paper sheds light on this issue by examining the continuous flow of collateral from clearing members to CCPs and then from CCPs back to financial markets. As illustrated in Figure 1, our study reveals that two crucial mechanisms are at play: First, the way in which CCPs collect margin creates a substantial and procyclical flow of cash from market participants to CCPs. Second, current regulation mandate CCPs to invest the collected cash in safe assets, thus effectively returning cash back to financial market participants. We provide compelling evidence that the combined effects of these two flows create persistent collateral cycles in which cash goes back and forth from financial markets to CCPs. Using supervisory data from UK CCPs, we demonstrate the systematic impact of these dynamics on repo markets. A difference-in-differences analysis of the policy-enforced migration of euro-denominated contracts from London-based to EU-based CCPs indicates that CCP regulation is a key determinant in the collateral cycle.

The onward phase of each collateral cycle is driven by the need for CCPs to collect initial margin to protect themselves against potential losses resulting from the default of any of their members. Our empirical analysis shows that the average level of initial margin pledged by the clearing members of the main UK CCPs, is around £185 billion, half of which is in cash. It is also well known that CCP margin requirements increase with market volatility, that is, in a procyclical manner. For visual evidence, Figure 2 shows that, at the peak of the COVID-19 pandemic in March 2020, the amounts of cash margin pledged with UK CCPs in the major currencies (USD, EUR and GBP) rose in tandem with implied market volatility.

What is less well known, however, is how CCP members obtain this cash and what effect CCP members have on funding markets by obtaining it. Our paper thus highlights the link between CCP margin requirements and the repurchase agreement (repo) market, which is one of the main sources of funding liquidity. We show that CCP cash margin is *also* procyclical with respect to repo rates. To display this, Figure 3 shows that the CCP cash margin tends to comove with repo rates, especially in times of stress. To hone in on the link between CCP cash initial margin and repo rates, we first study their lead-lag relationship. We find that every 1% increase in the repo rate is followed by a next-day average increase of £0.38 billion in the cash initial margin (IM) across UK CCPs, but this number increases to around £2 - £5 billion during times of stress, such as the COVID-19 pandemic.

We argue that the repo rate increase in anticipation of CCP margin requirements is suggestive of liquidity hoarding by clearing members. Specifically, clearing members first form clear expectations about the direction of future margin requirements. This is possible since the main principles governing the determination of CCPs' margins are well known. This incentivizes clearing members to then hoard liquidity by tapping repo markets in anticipation of margin payments (Gai et al., 2011), especially in times of stress (Bakoush et al., 2019). We provide more direct evidence of liquidity hoarding at the clearing member level. To do so, we utilize member-specific data on Sterling cash margin payments and repo transactions. Our analysis shows that UK CCP clearing members increase their borrowing and reduce their lending in the overnight Sterling repo market in anticipation of same-currency cash margin payments. We also show that this liquidity hoarding exerts upward pressure on clearing members' own repo borrowing rates. Taken together, these results help explain the procyclicality of CCP cash margin with respect to repo rates.[1]

The mechanism determining the backward phase of the collateral cycle is a regulatory requirement that CCPs invest their cash holdings in safe assets. In the case of European clearing houses, including UK CCPs, this requirement is articulated in the European Markets Infrastructure Regulation (EMIR), which states that at least 95% of any cash position that remains overnight in a CCP's margin accounts, or default fund, must be invested in reverse repos or government bonds or be deposited with a central bank.[2] Our data allow us to quantify and analyze how UK CCPs invest their cash holdings. For instance, the average outstanding investment in reverse repos by UK CCPs, over our sample period and across the major currencies (USD, EUR, GBP), is about £66.5 billion and that in bonds is £20.5 billion.

After documenting how CCPs invest their cash margin, we show that these investments by CCPs exert significant negative price pressure on interest rates. We discuss three potential channels through which CCP investments affect short-term repo rates. First, CCPs may exert a *direct* downward pressure on short-term repo rates when lending cash through reverse repos. Second, when purchasing safe bonds, CCPs may exert an *indirect* downward pressure on short-term repo rates. That is, bonds purchased by CCPs become scarcer (Krishnamurthy, 2002). Since these bonds are the collateral assets to secure repos, their scarcity makes them "special," thus lowering repo rates (Duffie, 1996) and increasing their convenience yield even in General Collateral repos (Ballensiefen and Ranaldo, 2023). Finally, the decline in long-term bond rates due to the price impact of CCPs' purchases can be transmitted to short-term rates through arbitrage activity consistent with the expectations hypothesis (Longstaff, 2000).

Our empirical findings show that both reverse repos and bond purchases conducted by CCPs, in compliance with existing regulations, exert downward pressure on repo rates.

[1] Later we also discuss how CCPs monitor the net present value (NPV) of clearing members' positions, as well as compute and charge the corresponding variation margins and the *price alignment interest* (PAI), which represents the overnight cost of collateral funding.

[2] See Articles 44-45 of EMIR (European Commission, 2013). EMIR has been onshored into UK legislation.

Furthermore, the size of this downward pressure increases at times of stress, that is, when CCPs request and obtain more cash from their clearing members. In particular, a one-standard-deviation increase in reverse repo volumes and bond purchases account for about 1.1% and 1.7% of the *daily* variation in repo rates, respectively. However, CCP reverse repos have a much more pronounced effect at times of stress. On days when market volatility attains its maximum value in our sample, reverse repos account for up to 14% of the daily repo rate variation, whereas bond purchases account for about 3%. These effects apply to every currency and they hold after controlling for the amount of liquidity provided by central banks in the form of reserves balances, as well as for aggregate risk measures. This implies that the existing regulation may have a countercyclical effect that helps alleviate increases in short-term funding costs associated with margin calls, particularly at times of stress.

To conclude our analysis, we investigate the 2019 policy-driven migration of EUR-denominated repos from London-based to EU-based CCPs. This exogenous event is analyzed in a difference-in-differences setting, revealing a significant, albeit economically small, weakening in the collateral cycle post-migration. Our findings suggest causal evidence that regulation is a critical determinant of collateral cycles.

Our findings should be of interest to policy makers. First, a better understanding of CCP margin procyclicality and of the underlying cash collateral flow is relevant because, as a result of post-crisis regulations, margin requests originating from CCPs simultaneously affect a large proportion of market participants. This could potentially create system-wide liquidity shocks as market participants scramble to source the necessary collateral in response to these margin calls. Thus, examining how margin calls relate to funding costs is an economically sensible way of capturing this liquidity risk.

Second, the post-crisis regulatory framework has also rendered CCPs themselves large actors in financial markets, where they "...act as major repo counterparties when reinvesting the large amounts of collateral they collect" (Cœuré, 2019). This means that CCP activity is potentially consequential for funding markets. For instance, the downward pressure on repo rates that we document could be important for monetary policy since money market rate dispersion between repo and other rates (Duffie, 2018) causes "a reduction in the efficacy and transmission of monetary policy" (Bank for International Settlements, 2017, p. 32).

Finally, some of the new policies and regulations that have been introduced since the financial crisis have also had unintended or unexpected effects. For example, the Basel III leverage ratio has created unintended adverse effects, such as dis-incentivizing repo intermediation (Duffie, 2018) and inducing collateral scarcity (Bank for International Settlements, 2017). In this context, we show that regulations governing CCP investments have a *countercyclical* effect on funding liquidity and pricing, thereby mitigating the procyclical effects due to margin calls.

Our work contributes to two strands of the academic literature that we survey in the next section. First, our paper adds to the literature on how the market structure and regulation affect financial markets. Our paper is the first to highlight the very existence of the cash collateral cycle and its significant effects on repo rates, both in the onward flow of cash from clearing members to CCPs and in the regulatory-driven backward flow from CCPs to financial market participants. Second, we contribute to the literature on safe assets, showing that the backward flow from CCPs' cash investments in repo markets and safe bonds exerts negative pressure on repo rates by increasing the supply of available cash and decreasing the supply of safe bonds.

The remainder of the paper is organized as follows. In Section 2, we review the related literature. In Section 3, we describe the institutional setting. In Section 4, we describe the data and present summary statistics. Section 5 contains our empirical results. Section 6 presents the difference-in-differences analysis of the migration of EUR-denominated repos. Section 7 concludes.

2 Literature Review

Our paper contributes to several areas of the literature on how the market design and legislative framework affect the functioning of financial markets and safe asset prices. The first is the nascent literature on the potential benefits and costs of central clearing. A number of studies argue that central clearing has many benefits, including a more efficient posting of costly collateral, insurance against counterparty risk (Acharya and Bisin, 2014), and mitigation of fire sales.[3] However, potential drawbacks are a factor too. For instance, the reliance of clearing members on a CCP may induce moral hazard, thus increasing systemic risk (Biais et al., 2012). Furthermore, compared to bilateral netting, multilateral netting operated by CCPs can reduce risk exposures within an asset class, but not (or less) so across asset classes (Duffie and Zhu, 2011).[4] Additionally, a clearing member's mark-to-market loss can exceed the posted collateral, resulting in a margin breach that can be systemically more relevant when many clearing members hold crowded positions (Menkveld, 2017) that cluster across time (Jones and Pérignon, 2013). Finally, a key concern around central clearing is margin procyclicality, that is, the tendency of margins to increase with risk (Murphy et al., 2014). This type of margin procyclicality can be destabilizing if it reinforces funding liquidity problems. For example, Bakoush et al. (2019) theorize that banks hoard liquidity from the interbank market in order to fund margin calls and that central clearing might in fact exacerbate systemic liquidity risk. Our paper directly addresses this issue by being the first that empirically analyzes the relation between CCP margins and funding costs.

Related to our paper is the discussion on the effects of central clearing on the demand for collateral. In addition to aggregate reported quantities of CCP collateral (e.g., CPMI-IOSCO, 2012, 2015), estimates of collateral demand are computed in Capponi et al. (2014), Ghamami and Samim (2017), Heller and Vause (2012), and Sidanius and Zikes (2012).

[3]See Menkveld and Vuillemey (2021) for an excellent survey of the literature.

[4]Cont and Kokholm (2014) extend Duffie and Zhu (2011) by including heterogeneous assets in terms of risk characteristics.

Duffie et al. (2015) show that central clearing actually lowers collateral demand relative to bilateral clearing through multilateral netting and diversification.[5] In addition to showing how clearing members meet the CCP demand for collateral (in terms of cash, securities, and in which currency), we contribute to this strand of the literature by uncovering a cash collateral cycle, whereby the cash margin received by CCPs is effectively returned to the financial markets via reverse repo transactions and bond purchases.

Finally, our paper is related to a growing number of studies on the impact of central clearing on asset prices. Loon and Zhong (2014) show that the premia of CDS contracts increase once these become centrally cleared, consistent with a reduction of counterparty risk. Cenedese et al. (2020) document that bilaterally cleared interest rate swaps are more costly to trade than their centrally cleared equivalents due to valuation adjustments induced by the post-crisis regulation. Benos et al. (2019) show that fragmentation in clearing. More specifically, if the same contracts are cleared by multiple CCPs, the resulting reduction in netting efficiency leads to these contracts being traded at different prices.

Given the investments that CCPs undertake in the form of reverse repos, some recent papers have also looked at the effects of clearing on repos, which constitute an important category of *safe assets* (Gorton, 2017). Mancini et al. (2016) show that in riskier markets, rates of European CCP-based repos secured by truly (quasi-)safe assets remain stable (increase) and their trading volumes increase (decrease) pointing to a convenience premium of the best collateral assets. Hüser et al. (2021) document that during stress periods market participants prefer to transact in the centrally cleared segment of the repo market and that CCPs increase their re-investment of cash margin into reverse repos. Ranaldo et al. (2021) show that the new EMIR regulation induces CCPs to supply large amounts of cash in reverse repurchase agreements (reverse repos) thus decreasing short-term rates.[6] In this context, our study is the first to show that the effect of CCP investments on repo rates is more pronounced in stressed periods and that the new mandatory framework (EMIR) has

[5]Other papers discuss the new regulatory setting (e.g., Cerezetti et al., 2018; Murphy, 2020) as well as risk modeling and measurement (e.g., Cruz Lopez et al., 2017; Huang and Takats, 2020).

[6]Munyan (2015) and Kotidis and van Horen (2018) study broader regulatory effects on repo markets.

a countercyclical impact on short-term funding costs. We are also the first to investigate the policy-enforced migration of EUR-denominated contracts, offering consistent evidence of the regulatory effects on collateral cycles.

3 Institutional Framework

In reference to Figure 1, it is important to explain why and how collateral cycles occur. We begin with the onward phase of the cycle, which is the left side of the figure, where collateral flows from clearing members to clearing houses. Through clearing, a CCP becomes a counterparty in every trade. In this role, the CCP contributes to credit risk mitigation and collateral efficiency. In turn, clearing members must satisfy initial margin (IM) requirements and contribute to other financial safeguards that mitigate credit risk in the event of a clearing member's default.[7] Importantly, IM requirements increase when market conditions worsen. For instance, a CCP will increase IM requirements in response to higher market volatility. To fulfil these requirements, clearing members must pledge a corresponding amount of cash or securities collateral with the CCP. Compared to non-cash (securities) collateral, cash collateral offers some advantages including lower haircuts (when cash collateral of a different currency is pledged than of the currency requested), being easier to handle, and being the only type of collateral accepted for variation margin in UK clearing houses. This is also why market participants tend to gravitate to cash collateral when conditions in financial markets are volatile.[8] Our first contribution is to highlight how clearing members perform this function and how doing so affects repo markets.

We now turn to the right side of Figure 1, which shows how cash collateral flows from

[7]CCPs collect two types of margin: Variation margin (VM) is intended to cover clearing members' current exposures as market conditions change. It is thus transferred via the CCP from one clearing member to another. IM is intended to cover clearing members' potential future exposures that may arise in case of a clearing member's default. IM is collected by the CCP from all clearing members, regardless of the current exposure of their portfolios. CCPs also collect contributions for the benefit of a default fund which is an additional resource aimed to cover losses that may arise in the case of a member's default. Unlike VM and IM however, these contributions are not calibrated on a daily frequency.

[8]The recent "dash for cash" episodes in a number of jurisdictions are a case in point.

CCPs back to financial markets. This backward phase is less known, and analyzing it is the second contribution of our paper. To understand the backward mechanism, a few observations are in order. First, CCPs hold a significant amount of collateral. For instance, CPMI-IOSCO Public Quantitative Disclosures in 2017 indicate that the aggregate initial margin requested by the top-10 EMIR-regulated CCPs from their clearing members was approximately 280 billion euro, half of which was submitted in cash. Second, while security collateral can be held by CCPs, EMIR states that at least 95% of any cash position in CCPs' margin accounts or default fund held overnight must be invested in a safe and liquid manner.[9]

The law essentially gives CCPs three options for complying with this rule: reverse repos, purchases of government bonds and central bank deposits.[10] There are several reasons why (reverse) repos are a favorable method of cash investment for CCPs. First, (overnight) reverse repos allow CCPs to obtain their invested cash the next day. This gives them more flexibility compared to a bond investment that requires one or two additional days (depending on the settlement convention) to be converted back into cash. Second, the repo market possesses such attractive features for CCPs as: (a) high liquidity, (b) a broad set of collateral assets, most of which are government bonds, such as German bunds, and (c) several General Collateral (GC) baskets that offer higher lending rates compared to

[9]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 [...]."

[10]Article 43 of the EMIR Delegated Regulation requires that financial instruments in which the CCP invests to be "debt instruments meeting each of the conditions set out in Annex II." (European Securities and Markets Authority, 2022). Specifically, the Annex II lists the conditions applicable to highly liquid financial instruments: (a) they are issued or explicitly guaranteed by a government bond, a central bank, a multilateral development bank, or the EFSF / ESM; (b) the CCP can demonstrate that they have low credit and market risk; (c) the average time-to-maturity of the CCP's portfolio does not exceed two years; (d) a currency the risks of which the CCP can demonstrate that it is able to manage; (e) they are freely transferable and without any regulatory constraint or third party claims that impair liquidation; (f) they have an active outright sale or repurchase agreement market, with a diverse group of buyers and sellers, including in stressed conditions and to which the CCP has reliable access; and (g) reliable price data on these instruments are published on a regular basis.

"special" (or specific) repos.[11] Thus, investing in a GC basket that satisfies the safety and liquidity requirements stipulated by law represents a more convenient and efficient option for CCPs. Third, the repo is a secured loan over a very short period. The vast majority of European repos are traded with one-day tenors[12] or a maturity no longer than one week. This makes CCPs' investment in reverse repos a flexible and effective way to comply with an additional regulatory constraint,[13] which is that the average time-to-maturity of CCP investment portfolios should not exceed two years (European Commission, 2013, p. 74). As such, reverse repos offer several advantages over (long-term) government bonds.

Regarding the other two options, only some CCPs have access to central bank deposits.[14] According to 2018 CPMI-IOSCO disclosures, for instance, some CCPs like Eurex Clearing, LCH SA, and CC&G had access to and deposited cash with central banks, while many others like EuroCCP, LCH Limited, and ICE could not or could do so only to a small extent. On the contrary, CCPs can regularly access the bond market. To comply with the regulation, however, CCPs can only purchase a selected set of specific government bonds of the highest credit quality and liquidity (or safe assets). Furthermore, compared to the repo market, the bond market is more segmented, as it is articulated into various maturities and debt-issuing nations, and longer-term financial securities expose CCPs to duration risk. Finally, the market regulator raises awareness that "diversification of investments possibilities can reduce risks, via the mitigation of collateral concentration and a reduction of the counterparty credit risk" (European Securities and Markets Authority, 2022). Since we do not have access to CCPs' individual investment positions, we cannot assess their portfolio risk and diversification policies. However, we do quantify the

[11]The asset being used as collateral can be a particular asset ("special repo") or any asset from a predefined basket of assets ("general collateral repo"). In the United States, a special repo is sometimes referred to as a "specific" repo, with the term "special" referring to specific repo rates being below prevailing short-term money market rates.

[12]The one-day tenors are overnight, spot-next, and tomorrow-next.

[13]See Hüser et al. (2021) for evidence.

[14]Some CCPs have no access to central bank facilities, either for regulatory reasons (because of the added cost of obtaining a banking license or because the local central bank does not wish to take on CCP risk) or because the financial instruments cleared by the CCP are not denominated in the currency of the local central bank (European Securities and Markets Authority, 2022).

aggregate CCPs' investments in repos and bonds.

4 Data and Summary Statistics

We combine three different supervisory data sets pertaining to the two largest UK-based CCPs: LCH Limited and the Inter-Continental Exchange (ICE) Clear Europe. The two CCPs in our sample account for around 94% of total cash collateral pledged across all UK CCPs over our sample period.[15] As such, our data cover the vast majority of clearing activity in the United Kingdom. The cash collateral pledged with the two CCPs spans seven different clearing services, each accounting for a particular asset class.

The first data set contains information on the amount of initial margin pledged with the two CCPs. In particular, for each clearing service of the two UK-based CCPs, we observe, on a daily basis, the stock of initial margin pledged from the clearing members and their clients in each of the main currencies: USD, EUR, GBP. We also observe the breakdown between cash and securities collateral pledged by the clearing members. Figure 4 shows that interest rate swap (IRS) contracts account for the majority of cash collateral pledged in these CCPs. The IRS category is followed by futures and options written on a variety of underlying assets.

Our second data set contains information on the CCPs' investment activity. In particular, we observe the aggregate daily outstanding positions in reverse repos and government bonds of each CCP, in each currency.[16] Given the size of the two London-based clearing houses in our sample, these investments correspond to a substantial fraction of the investments, in each of the three currencies, done by all CCPs globally.[17]

Our third data set consists of all Sterling denominated repo transactions that are

[15]The remaining is accounted for by cash collateral pledged with the London Metal Exchange (LME) Clear. Because of lack of data, we do not include this CCP in our sample.

[16]Unfortunately, we do not observe the counterparties to these CCPs' transactions, and, as such, we cannot precisely identify those market participants who receive cash from CCPs.

[17]For example, a comparison with CCP public quantitative disclosures, suggests that the reverse repo activity of the two CCPs in our sample, accounts for about 68%, 97% and 50% of the EUR, GBP and USD global CCP reverse repo volumes respectively.

cleared via the RepoClear service of LCH.[18] Since RepoClear is the main CCP for Sterling repos, this data set captures the vast majority of cleared Sterling repo transactions. Importantly, with this data set we can exactly identify the repo counterparties, which allows us to associate their repo activity with their margin payments.

Finally, we obtain from Bloomberg a number of market variables, such as implied equity market volatility indices in each currency. We compute general collateral overnight repo rates based on the same comprehensive data set used in Ballensiefen and Ranaldo (2023). All of our data sets span the period from February 2019 to June 2020, thus including the period of market stress associated with the COVID-19 pandemic.

Table 1 shows summary statistics for the aggregate variables used in our analysis. Panels A and B give some aggregate figures on the onward and backward phases of collateral cycles, respectively. Specifically, Panel A of Table 1 shows that the majority of outstanding cash margin ($CashIM$) is denominated in USD and is almost double what is being pledged in EUR and GBP. On the other hand, securities collateral is mostly split between US Treasuries and eurozone bonds at around double the amount of UK government bonds. This results in an approximate equal mix of cash and securities for the USD and GBP, whereas only about 36% of the euro-denominated collateral is in the form of cash, with the rest being securities. Another interesting feature is that the percentage of cash collateral varies substantially for each currency, fluctuating throughout our sample period by as much as 15%. As we will explore later in Section 5.1, this change in the collateral mix contributes to cash margin procyclicality.

Concerning the backward phase of collateral cycles, Panel B of Table 1 shows that these UK CCPs lend most of their cash on a secured basis using the repo market. The lending activity of the CCPs in our sample is consistent with the composition of the cash margin they receive and most of their reverse repos are USD-denominated. The second option used in terms of volume is the investment in government bonds, which is much smaller and concentrated in US Treasuries or other safe bonds. Specifically, the daily

[18] Hüser et al. (2021) utilizes the same data set.

average investment of cash by UK CCPs in our sample is about £66.5 billion via reverse repos and £22.5 billion in bonds. The predominant use of the reverse repo is consistent with the above-mentioned advantages it brings to CCPs, namely, the effectiveness of the contract design, safety, liquidity, and flexibility.

Given that our sample overlaps with the beginning of the COVID-19 pandemic, it captures both the elevated volatility in financial markets during this period and the associated central bank policy responses. This is reflected in the statistics for our market variables shown in Panel C, where both the implied volatility indices and the aggregate amounts of central bank reserves exhibit substantial variability. On the other hand, repo rates exhibit much less variation.[19] We will show later that this relative tranquility in repo rates, throughout this otherwise volatile period, is partly because of the countercyclical effect inherent in the backward mechanism of the collateral cycle.

5 Empirical Analysis

5.1 The Onward Phase and Cash Margin Procyclicality

We start our analysis by assessing the degree to which the cash initial margin (IM) is procyclical. The common understanding of this concept is that margins increase with volatility. Margin procyclicality is visible in Figure 2, which shows a tandem movement between margins and volatility intensifying at the peak of the COVID-19 pandemic in March 2020. The positive relationship between the two variables emerges systematically when regressing today's initial margins on yesterday's volatility, as shown in Table 2.[20]

What is less well known is the relation between margins and funding costs. More precisely, it is not clear whether the procyclicality of margin with respect to volatility also

[19]The maximum value of 5.25% for the USD overnight repo rate corresponds to the well-documented spike in USD repo rates on September 17, 2019. With the exception of this spike, USD overnight repo rates are relatively stable throughout our sample period.

[20]Given that margin payments are made daily, and sometimes intra-daily, the lagged relationship between margin and volatility mainly emerges because volatility is persistent; that is, yesterday's volatility is a good predictor of today's volatility.

extends to repo rates. The mechanism behind this additional procyclicality is based on the need of clearing members to meet margin requests from CCPs (Gai et al., 2011). As the models that determine CCP margins are sufficiently well known, they allow clearing members to form expectations about the likely evolution of margins as volatility increases. Thus, clearing members may revise their liquidity buffers in a consistent and procyclical manner (Bakoush et al., 2019) by tapping into the main segment of the money market, that is, the repo market. This liquidity hoarding could elevate repo rates, especially if repo borrowers are exposed to urgent liquidity needs, such as in periods of stress (Bechtel et al., 2022).[21] Of course, agents can consider alternative ways of obtaining short-term liquidity from financial markets, such as unsecured money market borrowing and asset liquidation. However, these options are generally less efficient, more costly, and unstable.[22] As a result, expected increases in cash IM induce clearing members to hoard liquidity by raising cash from repo borrowing or by refraining from giving away cash via repo lending. The large demand for cash (see Table 1) creates *upward* price pressure on repo rates and gives rise to a dynamic statistical relationship between repo rates and cash IM that we test as follows:

- *Hypothesis 1*: Repo rates rise in anticipation of increases in cash IM pledged with CCPs.

Such a relation would suggest that cash IM is also procyclical with respect to repo rates. Furthermore, the comovement between CCP cash IM and repo rates could be time-varying with this relationship becoming stronger at times of market stress when funding liquidity is likely to be scarce. As such, we also test the following hypothesis:

- *Hypothesis 2*: The procyclical relationship between the cash IM requested by CCPs and repo rates is stronger at times of high market volatility.

Here, we note that the relations described in these hypotheses are statistical in nature and do not have a direct causal interpretation. That is, we do not argue that repo

[21] Acharya and Skeie (2011) propose a theoretical model in which a financial firm's propensity to hoard liquidity increases with its exposure to rollover risk.

[22] For instance, the unsecured money market segment is much smaller than the secured one, and it is subject to counterparty credit risk, while liquidation of assets can trigger "fire sales" and liquidity spirals.

rates "cause" changes in the cash margin. Rather, the economic mechanism at play is that expected changes in the cash margin induce clearing members to hoard liquidity, which results in increases in repo rates. However, casting this relation in the form of our hypotheses makes economic sense because from the point of view of both CCP clearing members and regulators, it is important to know if clearing members are likely to encounter elevated funding costs whenever they need to fund their upcoming margin payments.

To test these hypotheses, we estimate the following empirical panel specification:

$$\begin{aligned} CashIM_{it} =& a + bCashIM_{it-1} + c_1 \Delta Repo_{it-1} + c_2 Stress_{it-1} \\ &+ c_3 Stress_{it-1} \times \Delta Repo_{it-1} + v_i + u_{it}, \end{aligned} \tag{1}$$

where i denotes currency, t denotes days, $CashIM$ is the aggregate cash initial margin pledged with the UK CCPs in our sample, in each currency, and $Repo$ is the currency-specific overnight repo rate. $Stress$ is an indicator of stressed market conditions. We consider two stress indicators: First, a time dummy variable taking the value of one from February 19, 2020, that is, during the period of heightened market volatility due to the COVID-19 pandemic. Second, we measure market stress with a currency-specific implied stock market volatility index. The specification includes a first lag of the cash IM to control for persistence in this variable, and we also include the repo rate in differences so as to render it stationary.[23] The specification is estimated using currency fixed effects with standard errors being clustered by currency.[24] As mentioned above, this specification is purely predictive in that it captures dynamic correlations and should not be interpreted as causal. The goal is to identify any instances of cash margin procyclicality with repo

[23]The inclusion of a lagged dependent variable in our panel regression does not bias our results on account of the long time dimension ($T = 346$) of our sample.

[24]It is well known that the repo market has been characterized by quarter-end seasonal patterns, especially in jurisdictions whose regulations dictate "monthly averaging," rather than "daily averaging." The United Kingdom adopted the latter method in 2017, and the Sterling repo market is no longer affected by these patterns (Kotidis and van Horen, 2018). This should not be an issue for our analysis because our sample period starts in 2019. To be sure, however, we reran all regressions by removing the last trading day of the month and quarter and the results remained qualitatively similar.

rates as per our hypotheses. The results for this estimation are shown in Table 2 (columns 3-5). Two findings stand out: First, CCP cash IM is (also) procyclical with respect to repo rates. Second, this relation appears to be stronger at times of stress as indicated by the significant coefficient for the interaction term between repo rates and VIX. These coefficients suggest that a 1% increase in the repo rate is associated with a next-day increase in aggregate cash IM by £0.38 billion across UK CCPs over the entire sample period. However, this increases to £2.44 billion during the COVID-19 pandemic (i.e., after February 19, 2020) and to £4.61 billion when volatility attains its maximum value in our sample.[25] Overall, these findings point to margin-repo rate procyclicality, consistent with (time-varying) liquidity hoarding.

5.1.1 Relative Cash Margin Procyclicality

When issued a margin call by the CCP, clearing members have the option to pledge either cash or eligible securities as collateral. For a visual inspection of how the composition of collateral pledged with CCPs evolves over time, we compare in Figure 5 the aggregate cash IM pledged across UK CCPs with the ratio of cash over total collateral pledged by clearing members. It is notable that the relative amount of cash pledged as collateral with CCPs comoves with total cash IM. This implies that variations in the levels of cash IM are partly driven by changes in the composition of CCP pledged collateral with clearing members shifting toward cash.

In Section 3, we discussed some of the institutional and regulatory reasons a clearing member might prioritize cash collateral rather than securities. For example, clearing members could be accumulating cash in anticipation of market volatility and the associated variation margin payments that are payable in cash.[26] If clearing members then acquire sufficient cash, they might use proportionally more of it to meet their IM obligations.

[25] If one were to estimate the longer-term correlation between changes in repo rates and aggregate cash IM, by accounting for the first lag of cash IM, then these numbers would be substantially higher at £4.22 billion, £30.5 billion, and £51.26 billion, respectively.

[26] Corroborating this, Huang and Takáts (2020) document a significant increase in cash holdings for US banks ahead of the COVID-19 pandemic in March 2020.

Given that clearing members tap repo markets to obtain their cash and can move repo rates by doing so, this would give rise to a positive dynamic relationship between repo rates and the *proportion* of cash pledged as collateral. This intuition motivates the next hypothesis that we test:

- *Hypothesis 3*: Repo rates rise in anticipation of increases in the proportion of cash IM pledged as collateral with CCPs.

To formally test this hypothesis, we estimate the following panel specification:

$$\begin{aligned} CashIM(\%)_{it} =& a + bCashIM(\%)_{it-1} + c_1 \Delta Repo_{it-1} + c_2 \Delta Reserves_{it-1} \\ &+ c_3 Stress_{it-1} + c_4 \Delta Repo_{it-1} \times Stress_{it-1} + v_i + u_{it}, \end{aligned} \tag{2}$$

where, as before, i denotes currency and t denotes days. $CashIM(\%)_{it}$ is the ratio of cash over total margin (i.e., cash plus securities) pledged with UK CCPs by their clearing members, *Repo* is the currency-specific overnight repo rate, *Stress* is the previously used indicator of stressed market conditions and *Reserves* are the aggregate central bank reserves in each currency. This variable acts as a control for the effects of (unconventional) monetary policies, such as Quantitative Easing programs that inject liquidity in the financial system by expanding central bank balance sheets. In fact, the decision to pledge proportionally more cash or securities may well depend on the aggregate amount of liquidity available in the form of such central bank reserves balances.[27] As in the previous specification, we include the first lag of $CashIM(\%)$, the repo rate in differences, as well as currency fixed effects.

The results of this estimation are shown in Table 3. As one can see, increases in the repo rate predict increases in the percentage of cash pledged as CCP collateral, even when controlling for volatility and central bank liquidity. This result indicates that the proportion of margins pledged as cash rather than securities increases right after an increase in

[27] Although reserves would not have increased immediately, there may have been "announcement effects" of the Quantitative Easing programs that could have also indirectly impacted the confidence on the correct functioning of the repo market.

funding costs. As mentioned earlier, this is consistent with cash hoarding because the increase in repo rates could be caused by market participants tapping repo markets to raise the desired amounts of cash. However, this effect does not appear to be time-varying because the coefficients on the interaction terms are insignificant.

5.1.2 Clearing Member Liquidity Hoarding

So far, we have argued that the procyclicality between cash IM and repo rates is suggestive of liquidity hoarding by clearing members. In this section, we provide additional direct evidence of this effect by analyzing the repo market activity of *individual clearing members* of UK CCPs. For this purpose, we combine our data on clearing members' Sterling-denominated cash margin with the data on their activity in the Sterling repo market. Liquidity hoarding would occur if individual clearing members tap repo markets to accumulate cash *in advance* of expected margin payments. Accumulating cash in repo markets, in turn, occurs when clearing members borrow more and lend less.

Furthermore, repo rates will be rendered procyclical with respect to cash margin payments if the increased borrowing and reduced lending by clearing members has an impact on their borrowing costs. Thus, we postulate the following hypotheses:

- *Hypothesis 4a*: Clearing members hoard liquidity in anticipation of cash margin payments by borrowing (lending) more (less) in the repo market *ahead* of cash IM payments.
- *Hypothesis 4b*: Clearing members' increased borrowing and reduced lending in the repo market exert upward price pressure on their borrowing costs.

To test *Hypothesis 4a*, we estimate the following panel specification:

$$\begin{aligned} CashIM_{jt} =& a + bCashIM_{jt-1} + c_1 ON\_Repo\_Borrowing_{jt-1} + c_2 ON\_Repo\_Lending_{jt-1} \\ & + dVIX_{t-1} + v_j + u_{jt}, \end{aligned} \tag{3}$$

where j denotes clearing members and t denotes days. The dependent variable is the cash IM pledged, exclusively in Sterling, by each clearing member, across the clearing services of CME and LCH (the UK CCPs in our sample). $ON\_Repo\_Borrowing$ ($ON\_Repo\_Lending$) is the daily overnight borrowing (lending) volume by clearing members in the Sterling repo market. Given that the repo transactions in our sample are overnight, and whose second leg settles the next day, we use lagged values for these variables to account for potential liquidity hoarding over the day prior to the cash margin being paid.[28] Finally, VIX is (in this case) the 30-day implied volatility of the FTSE 100 UK equity market index. This is included to control for the effects of market risk on posted cash margin.

To test *Hypothesis 4b*, we estimate the following panel specification:

$$\begin{aligned} Repo_{jt} =& a + bRepo_{jt-1} + c_1 ON\_Repo\_Borrowing_{jt} + c_2 ON\_Repo\_Lending_{jt} \\ & + d\Delta CDS_{jt-1} + v_j + u_{jt}, \end{aligned} \tag{4}$$

where as before j denotes clearing members and t denotes days. The dependent variable is the volume-weighted average overnight borrowing repo rate of each clearing member. The main independent variables are the same as in the previous specification, and CDS is the CDS spread of each clearing member controlling for its credit risk (Bechtel et al., 2022).[29]

Table 4 shows summary statistics for the clearing-member-specific variables (Panel

[28]Sterling cash margin intended to cover overnight margin calls is due at 9:00 am London time for LCH and 10:00 am for ICE Clear. In the case of LCH, the calls themselves are sent by 8:00 am in the morning giving clearing members an hour to replenish their margin accounts, should that be necessary. For more information on LCH collateral management processes, see `https://www.lch.com/collateral-management/ltd-collateral-management/ltd-acceptable-collateral/ltd-acceptable-cash`. For ICE Clear, see `https://www.theice.com/clear-europe/treasury-and-banking`.

[29]The repo transactions in our sample are centrally cleared and therefore one might expect the impact of clearing member credit risk on repo rates to be limited. However, the anonymous and centrally cleared segment of the Sterling repo market is only a fraction of the overall Sterling repo market. As such, riskier clearing members might be willing to borrow at a higher rate in the cleared segment, if faced with higher borrowing costs in the uncleared one. Unfortunately, we do not observe clearing members' transactions in the uncleared segment and thus cannot empirically confirm this hypothesis.

A) and the regression specification results (Panels B and C). These results first show that clearing members increase their overnight borrowing and decrease their overnight lending in the Sterling repo market ahead of increased cash margin payments in the same currency. This is consistent with clearing member liquidity hoarding by both tapping into repo markets and reducing repo lending in anticipation of margin payments. This effect is consistent with the cash margin being procyclical with respect to repo rates, as discussed in previous sections.

Second, the results show that liquidity hoarding by clearing members elevates their funding costs, thereby supporting the idea that repo borrowers exposed to urgent liquidity needs are willing to pay a markup for immediate funding (Bechtel et al., 2022). Taken together, anticipatory liquidity hoarding and its contemporaneous repo rate impact explain why cash margin pledged with UK CCPs is procyclical with respect to repo rates.

At this point, it is also worth noting that the effects we have described so far collectively imply that at times of high market volatility and stress increased amounts of cash (in both absolute and relative terms) are transferred from funding markets to CCPs. We have provided evidence that this occurs at the clearing member level and this is supportive of the liquidity hoarding hypothesis. This flow constitutes the onward phase of the cash collateral cycle between CCPs and their clearing members. The next step is the analysis of the backward phase.

5.2 The Backward Phase and CCP Investment Activity

As discussed previously, the EMIR legislative framework, under which UK CCPs operate, mandates that CCPs invest the vast majority of their cash collateral in a safe and liquid manner, that is, by lending it on a secured basis, by investing in safe bonds, or by depositing it with a central bank account. What our summary statistics revealed is that the cash amount invested daily by CCPs is substantial and that most of the cash collateral pledged with UK CCPs is reverse repoed, with a smaller fraction being invested in bonds (Table

1, Panel B).[30] Given that our data include information on both daily CCP investments (in bonds and reverse repos) and collected cash IM, it allows us to thoroughly examine the relation between cash collateral pledged and CCP investment activity.

Figure 6 shows the amount of cash pledged across all UK CCPs alongside their daily aggregate government bond investments and reverse repo volumes. It is evident that both reverse repo volumes and bond purchases comove with the amount of cash collateral pledged with CCPs, and this movement is particularly pronounced during the market events associated with the COVID-19 pandemic. This suggests that at times of higher volatility and thus higher levels of accumulated cash collateral, CCPs return increased amounts of this cash back to the market. This flow constitutes the *backward* phase of the collateral cycle. Motivated by this discussion, we test the following hypothesis:

- *Hypothesis 5*: The more cash collateral is pledged with CCPs in a particular currency, the *larger* the amount of reverse repo and bond investment activity by CCPs in the same currency.

Using our daily time series for each currency, we test this hypothesis by estimating the following panel specification:

$$CCP\_Inv_{it} = a + \sum_{k=0}^{5} b_k \Delta CashIM_{it-k} + cStress_{it-1} + v_i + u_{it}. \tag{5}$$

Our dependent variable CCP_Inv is the daily aggregate and currency-specific investment by UK CCPs in either bonds ($\Delta Bonds$) or reverse repos ($VlmRR$). $CashIM$ is the absolute aggregate level of cash in each currency pledged with CCPs, and $Stress$ denotes our indicators for stressed market conditions. We use up to five lags of the daily changes in $CashIM$ for two reasons. First, we are agnostic about the time it takes a CCP to invest its cash collateral, and we therefore want to capture any lagged effects asssociated with this process. Second, since CCPs engage in overnight reverse repos, these have to be rolled over on a daily basis. As a result, an increase in cash collateral could potentially

[30] For a detailed description of the investment choices of several global CCPs, see Holden et al. (2016).

increase CCP reverse repo volumes over a few subsequent days. This specification, too, features currency fixed effects, and inference is done by clustering at the currency level.

The results for this specification are shown in Table 5 for reverse repo volumes (columns 1-3) and bond investments (columns 4-6). They suggest that both CCP reverse repo volumes and bond investments in a given currency positively respond to the amount of cash collateral pledged in the same currency over the previous five days, with the effects being statistically stronger for reverse repo volumes as indicated by the associated F-tests.

It is also worth noting that the sum of lagged $CashIM$ coefficients is greater than one in the case of reverse repo volumes but less than one in the case of bond investments. In particular, a one-standard deviation increase in cash collateral (£1.28 billion) leads to a cumulative increase in CCP reverse repo volume over the next five days by about £3.4 billion and to a cumulative increase in bond investments by about £0.2 billion. The larger cumulative effect for reverse repos is driven by the subsequent rolling-over of these reverse repo positions on a daily basis.

As mentioned earlier, the result that CCP investments (reverse repos and bond purchases) respond to changes in same-currency cash IM implies a cash collateral cycle that siphons liquidity back to the market with the "recycled" amount being higher at times of stress, that is, when cash IM also increases. This is important because it implies that this part of the cash collateral cycle might have a *countercyclical* effect if CCP investments also affect prevailing repo rates. We will turn to this question next.

5.3 Countercyclical Effects of the Cash Collateral Cycle

Having documented that CCPs recycle a large proportion of the cash they receive as IM collateral, an important question is how this recycling affects funding costs. At least three mechanisms can lead to a decrease in repos rates. First, the considerable flow of cash into the repo market by CCPs should exert a *direct* downward pressure on short-term rates. Second, CCP bond purchases should also exert an *indirect* downward pressure on short-term rates. Specifically, purchased bonds become scarcer, and their reduced net supply forces bond investors to accept a price premium (Krishnamurthy, 2002). Bond scarcity makes these assets "special" in the repo market, thus lowering their associated repo rates (Duffie, 1996). Notice that the asset scarcity leads to an increase of the convenience yield, even if the asset is part of a General Collateral basket (Ballensiefen and Ranaldo, 2023). Third, the decline in long-term bond rates due to the price impact of CCPs' purchases may be transmitted through the interest-rate term structure; that is, the downward adjustment of short-term rates might reflect that of longer-term rates consistent with the expectations hypothesis (Longstaff, 2000).

Taken together, these effects would suggest that the backward phase of the collateral cycle, whereby CCPs return cash to financial markets, lowers repo rates. Ranaldo et al. (2021) provide evidence that CCP reverse repo volumes exert downward pressure on repo rates. Here, we extend their analysis in two ways. First, we examine whether CCP bond purchases, in addition to CCP reverse repos, have a downward effect on repo rates. This matters because, if true, it could mean that the upward pressure on repo rates induced by CCP initial margin calls is partially offset by CCP investment activity. In addition, during times of higher volatility and margin requests, this effect would be even stronger since more cash would be channeled back to the market via CCPs, as documented in the previous section.[31] In other words, Ranaldo et al. (2021) study only part of the backward phase of collateral cycles, while we study both the onward and backward phases that jointly give rise to the collateral cycle. Second, our sample covers a different time period characterized by larger amounts of aggregate liquidity.[32] This is due to accommodating central bank policies, which were further expanded as a result of the COVID-19 pandemic in United States, the United Kingdom, and the eurozone. The larger amounts of available liquidity may have thus changed the relative importance of the effects on repo rates described above as they simultaneously render cash more abundant and government bonds more scarce.

[31]Of course, this would only be true as long as there are no clearing member defaults; in the case of default, CCPs would instead use their cash collateral to cover their losses.

[32]For example, the aggregate amount of euro reserves balances issued by the ECB averages about 2.5 trillion during our sample period, whereas it is on average about 1 trillion during the period studied by Ranaldo et al. (2021).

This discussion motivates the following hypotheses:

- *Hypothesis 6*: The repo rate is negatively associated with the size of CCP reverse repo activity and outright bond purchases.
- *Hypothesis 7*: The negative effects of CCP reverse repos and outright bond purchases on repo rates are countercyclical; that is, they are more pronounced at times of higher market volatility.

To test these hypotheses, we estimate the following panel specification:

$$\begin{aligned} Repo_{it} = a &+ b_1 Repo_{it-1} + b_2 VlmRR_{it-1} + b_3 \Delta Bonds_{it-1} + b_4 \Delta Reserves_{it-1} \\ &+ b_5 VIX_{it-1} + b_6 (VIX_{it-1} \times \Delta Reserves_{it-1}) + b_7 (VIX_{it-1} \times VlmRR_{it-1}) \\ &+ b_8 (VIX_{it-1} \times \Delta Bonds_{it-1}) + v_i + u_{it}, \end{aligned} \tag{6}$$

where i and t denote currencies and days, respectively. *Repo* is the overnight repo rate in currency i, $VlmRR$ is the aggregate volume of reverse repos in currency i across all UK CCPs, *Bonds* is the total amount of government bond investments in currency i by UK CCPs, *Reserves* is the aggregate amount of central bank reserves balances in currency i, and VIX is the implied volatility for a broad equity market index in each currency. We include in the model three interaction terms that are intended to capture any countercyclical effects, that is, whether the impact of central bank reserves and CCP investment activity (i.e., reverse repos and bond purchases) vary with aggregate market volatility. We include a first lag of the repo rates to account for persistence in this variable and otherwise difference all variables for which we cannot reject the presence of a unit root.[33] The specifications nested in this model are all estimated using fixed effects, while the standard errors are clustered by currency.

Table 6 shows the estimation results. The first finding to notice is that CCP investment activity has a negative impact on repo rates, consistent with the findings in Ranaldo et al.

[33]As a result of differencing, our estimation method is highly conservative.

(2021) (columns 1-3). However, there are two new results. First, CCP investments in bonds also have a statistically significant effect on repo rates and in fact more so than CCP reverse repo volumes.[34] This suggests that during our sample period which includes the pandemic and massive quantitative easing programs, repo rates are also reduced because of the scarcity of collateral securities, as well as an abundance of cash (central bank reserves). This also suggests that the indirect effect of CCP bond purchases on repo rates may have gained strength over our sample period relative to the direct effect of reverse repo volumes. In fact, after controlling for aggregate liquidity, we find the effect of reverse repo volumes disappears, while that of bond investments persists (column 6).

Second and most importantly, our results also suggest that the effects of CCP investments on repo rates are *countercyclical* in that they become stronger when market volatility is high. This is indicated by the significantly negative coefficients in the interaction terms between the volatility index and *both* CCP reverse repos and bond purchases (columns 8 and 9). This means that the countercyclical effect of CCP investments is transmitted via both the cash and securities channels.

These effects are economically significant as well. The estimated coefficients in columns 1 and 2 suggest that a one-standard-deviation increase in reverse repo volumes (£3.14 bn) and daily bond purchases (£0.29 bn) accounts for about 1.1% and 1.7% of the daily variation in repo rates, respectively.[35] However, CCP reverse repos have a much more pronounced effect at times of stress. On days when market volatility attains its maximum value in our sample, reverse repos account for up to 14% of the daily repo rate variation whereas, bond purchases account for about 3%. This effect applies, on average, across all

[34] Given that CCPs can choose whether to reverse repo their cash collateral or invest it in bonds, the effect of CCP reverse repo trades on repo rates could be potentially endogenous. However, given that CCPs would likely execute reverse repo trades when it is more profitable to do so (i.e., when repo rates are higher), the resultant bias would go in the opposite direction of our reported results. This means that should there be a bias, it would conservatively reduce the negative effect of CCP reverse repo trades on repo rates.

[35] To obtain, for example, the effect of CCP reverse repos, we multiply the reverse repo volume coefficient from column 1 (-0.002) with the daily standard deviation of reverse repo volumes (£3.14 bn) and then divide this product with the daily standard deviation of repo rates (0.36%).

three main currencies in our sample.[36]

Overall, these results show that CCPs set in motion cash collateral cycles consisting of an onward and a backward phase, both of which have measurable effects on repo markets. In the former, the well-known procyclicality between CCP margins and volatility has consequences for repo rates, rendering them procyclical as well. In the latter, the regulatory-driven cash investment by CCPs has significant countercyclical effects on repo rates. This could at least partly explain why repo rates remain relatively subdued, even at times of stress, such as during the period of the COVID-19 pandemic, which is covered in our sample.

6 The migration of EUR-denominated repos

In this section we exploit the migration of EUR-denominated repo volumes from LCH Limited (in London) to LCH SA (in Paris), in February 2019, to provide further support for several of our hypotheses. To our knowledge, ours is the first paper to utilize this important market event in a study.

Against the backdrop of the UK's departure from the European Union (EU) and repeated calls by EU authorities for London-based clearing in EUR denominated contracts to migrate to EU-based CCPs, clearing in EUR-denominated repos shifted almost entirely from London to Paris on the 19th of February, 2019. This move appears to have been planned by clearing members in consultation with LCH and was justified on the basis that it allowed clearing members "...to consolidate euro repo and bond clearing in one place to obtain efficiency savings".[37]. Using our proprietary trade data, we plot in Figure 7 the daily EUR-denominated repo volumes and number of trades processed by RepoClear. As one can see, the migration out of LCH Limited in EUR repos was both nearly total and

[36]Note that the smaller effect of CCP bond investments is exclusively because of their smaller size relative to reverse repos.

[37]See `https://www.reuters.com/article/us-britain-eu-clearing-idUSKCN1QA2EY/`. Furthermore, note that this event occurred at a time when EUR repo rates were close to a historically low level so it is highly unlikely that the migration itself was influenced by repo market conditions.

permanent.

We exploit this exogenous event to provide further evidence in support of our hypotheses, offering more direct insight into the effects of regulation on the collateral cycle. In particular, we hypothesize that the collateral cycle induced by UK CCPs will likely have *weakened* as a result of EUR-denominated repos migrating to Europe. This is because there will be less margin being requested and posted for these trades since the migration was presumably carried out in order to realize netting efficiencies with EUR-denominated repo positions already cleared through LCH SA in Paris.

At this point we should mention that the effect of the EUR repo migration on the collateral cycle is likely to be economically small. Figure 4 shows that RepoClear accounts for less than 5% of the total cash IM in our sample and this includes IM posted in all main currencies and not just the EUR, which is the one affected by the migration. Table 7 shows average daily cash IM amounts requested and posted with RepoClear before and after the migration day. One can see that there is a (statistically) significant drop in EUR IM requested by RepoClear but no such drop for the other two currencies. Furthermore, the amount of cash IM posted both with RepoClear as well as with all other clearing services drops more for the EUR than it does for the other currencies. Nevertheless, the amounts involved are small with daily EUR cash IM dropping by only about £1.6 billion.

The small amounts suggest that any effects on the collateral cycle would likely also be small statistically and economically. However, testing for such effects is useful as this would provide additional support for the key hypotheses in our paper. Our key prediction is that the dynamic relationship between cash IM and repo rates will weaken as a result of the EUR repo migration. Given that only EUR-denominated repos migrated to Paris whereas USD and GBP-denominated ones continued to clear in London, we test this by estimating two difference-in-differences variations of models (1) and (2) over a short period around the EUR repo migration:

$$\begin{aligned} CashIM_{it} =& a + bCashIM_{it-1} + c_1\Delta Repo_{it-1} + c_2 Event_t \\ &+ c_3 Event_t \times EUR_i \times \Delta Repo_{it-1} + v_i + u_{it}, \end{aligned} \tag{7}$$

and

$$\begin{aligned} CashIM(\%)_{it} =& a + bCashIM(\%)_{it-1} + c_1\Delta Repo_{it-1} + c_2\Delta Reserves_{it-1} \\ &+ c_3 Event_t + c_4 Event_t \times EUR_i \times \Delta Repo_{it-1} + v_i + u_{it}, \end{aligned} \tag{8}$$

where i denotes currency and t denotes days. As before, the dependent variables are $CashIM$ and $CashIM(\%)_{it}$. The first is the aggregate cash initial margin pledged with the UK CCPs in our sample, in each currency, while the second is the ratio of cash over total margin (i.e., cash plus securities) pledged with UK CCPs by their clearing members. *Repo* is the currency-specific overnight repo rate, *Event* is a dummy variable that takes the value of 1 after February 19, 2019 and 0 before that and EUR is a dummy variable that takes the value of 1 for EUR and 0 for USD and GBP. The models are estimated over the period between February 8 and March 4, 2019, approximately 10 ten days before and after the EUR repo migration. For both models we use currency fixed effects and standard errors are clustered by currency.

The coefficients of interest are those of the interaction terms which capture any incremental changes in the relationship between EUR cash IM and repo rates relative to the other two currencies in the wake of the EUR repo migration. The results of these regressions are reported in Table 8. As one can see, the coefficients of the interaction terms are negative and marginally significant at or close to the 10% level. This suggests that the migration of EUR repo contracts away from LCH Limited was associated with a small but measurable weakening of the collateral cycle. That is, the relationship between EUR repo rates and EUR Cash IM became weaker in the wake of the migration compared with the other two currencies. As mentioned earlier, the small amounts of cash IM involved in EUR repo trades likely account for the statistically weak effect that we detect.[38]

7 Summary and Concluding Remarks

Using supervisory data from UK CCPs, our study reveals that cash collateral follows persistent cycles that comprise two phases. In the onward phase, cash collateral flows from clearing members to clearing houses (CCPs) in order to fulfil CCP margin requirements. This flow is known to be procyclical, that is, CCPs' initial margin (IM) increases with market volatility. Our analysis shows that repurchase agreement (repo) rates increase in anticipation of larger CCP cash margin payments, suggesting that clearing members hoard liquidity to meet them. This suggests that IM is *also* procyclical with respect to repo rates. Furthermore, this effect is more pronounced in times of stress and higher volatility.

In the backward phase, cash collateral flows back from CCPs to financial markets. This part of the collateral flow is driven by CCPs complying with the law. More specifically, to comply with the EMIR regulation, CCPs reinvest cash via reverse repos and government bonds. Our analysis shows that CCP reverse repos and bond investments exert downward pressure on repo rates. As CCPs' reinvestment of collateral increases with volatility, the negative effect on repo rates becomes countercyclical.

Such an effect should be of interest to regulators and the subject of further study. From a financial stability perspective, our work highlights how key parts of the financial system are interconnected and in particular, how the collateral cycle depends on the smooth functioning of repo markets, which periods of stress may impede. Focusing on the CCP investment leg of the cash collateral cycle, our findings matter for two reasons:

[38]We also estimate difference-in-differences variations of models (5) and (6). The main result from these tests is that the backward phase of the collateral cycle is unaffected by the EUR repo migration. While posted EUR cash IM decreases in the wake of the migration, the fraction of that IM that is invested by CCPs in bonds and reverse repos increases. As a result, the migration of EUR repos has no discernible overall effect on the sensitivity of EUR repo rates to CCP investments. These results are available upon request.

On the one hand, CCPs' investment policies appear to have a partially offsetting effect on funding markets, which is desirable, especially in stressed times. On the other hand, CCPs are only able to return their cash collateral to the market if it is not needed to cover losses from a potential default of a clearing member, which is more likely to materialize in highly stressed periods. Thus, the cash collateral cycle documented in this paper could potentially be broken if CCPs are not able to reinvest liquidity collected from clearing members and cannot transfer it back to market participants. Although an extreme scenario, this potential systemic adverse scenario deserves further research and reflection by policy makers.

Figure 1: The Cash Collateral Cycle

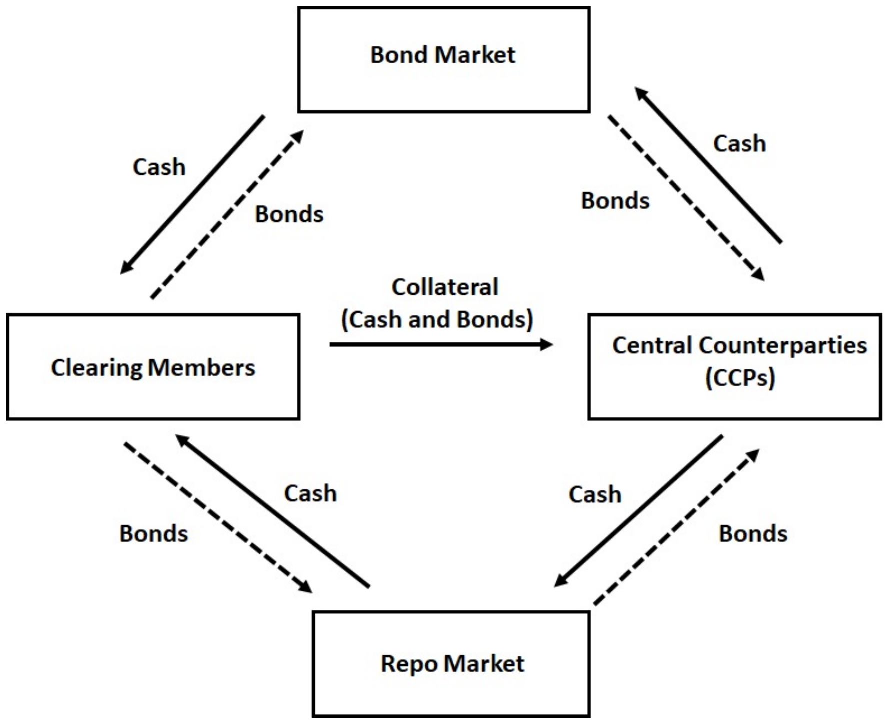


Figure 2: Initial margin and volatility This figure shows the time series of the aggregate cash initial margin across UK CCPs and average implied market volatility. The cash initial margin (converted to GBP) is paid in the three major currencies: USD, EUR, and GBP. The implied volatility index is the average of the VIX, VSTOXX, and IVUKX30 indices. The time period is from February 2019 to June 2020.

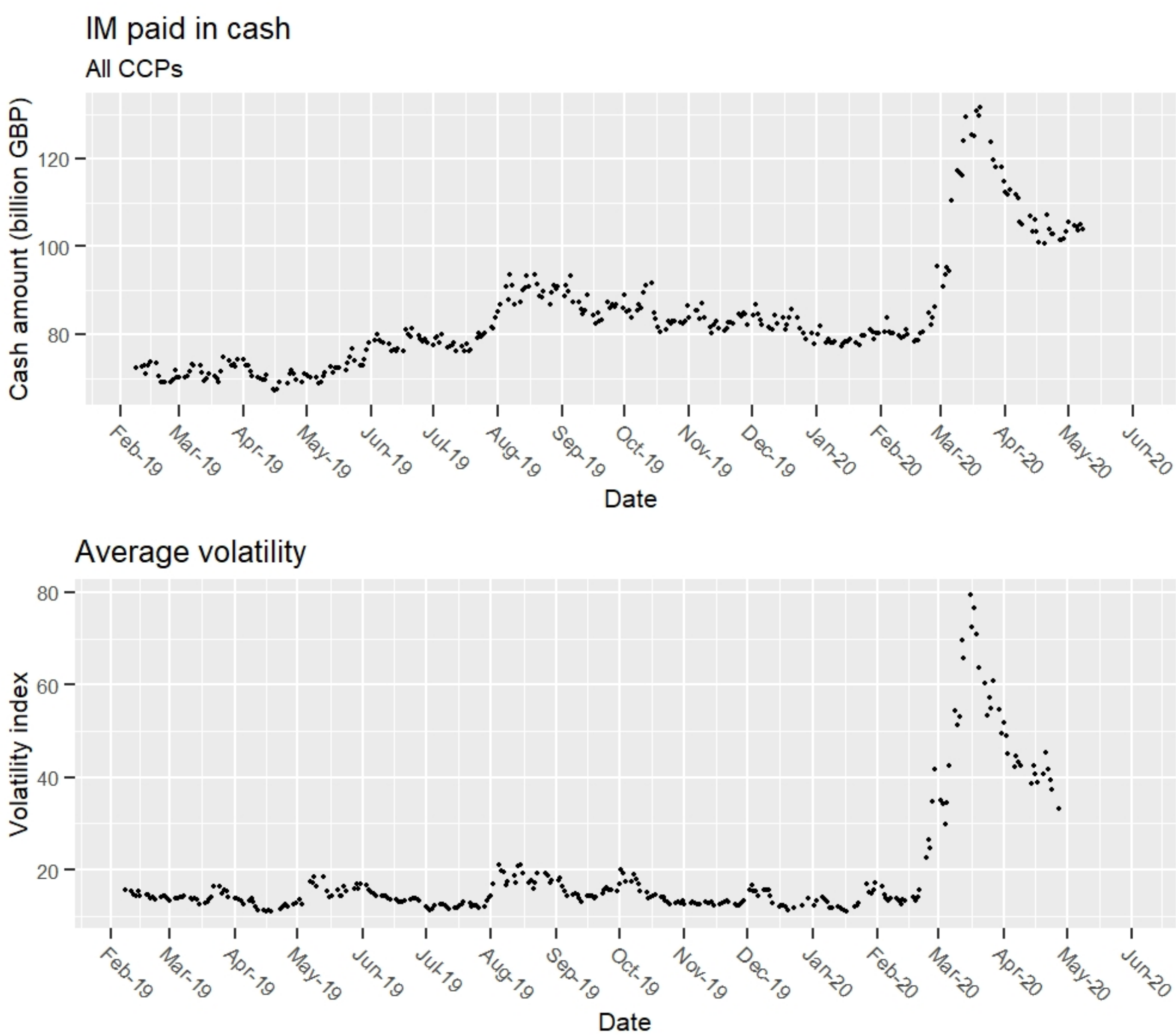
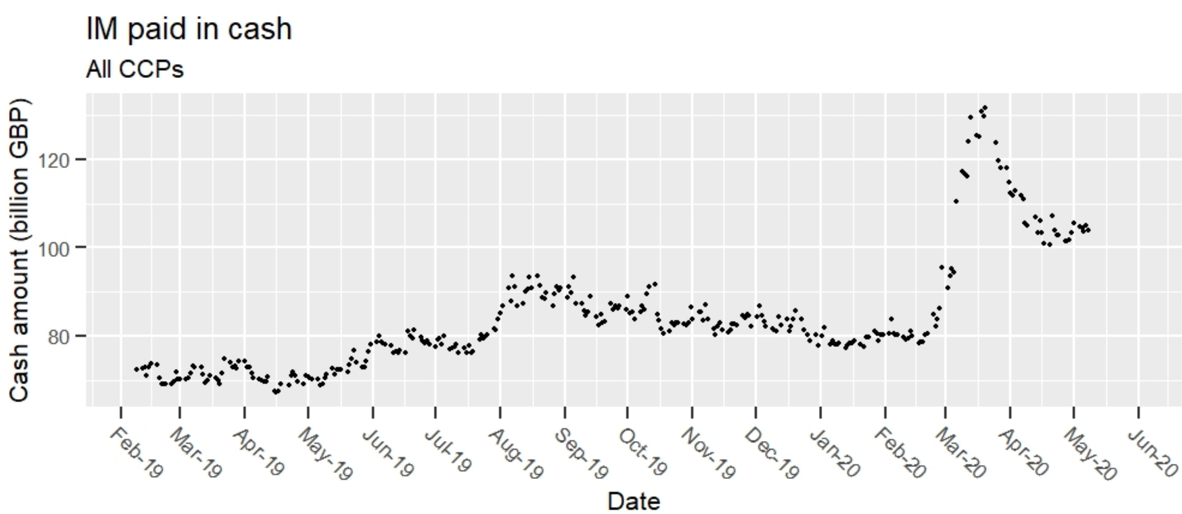


Figure 3: Initial margin and repo rates This figure shows the time series of the aggregate cash initial margin across UK CCPs and average adjusted repo rates. The cash initial margin (converted to GBP) is paid in the three major currencies: USD, EUR, and GBP. To aid visualization, we adjust the overnight repo rates for these currencies by subtracting the central bank policy rate and then averaging across currencies. The time period is from February 2019 to June 2020.



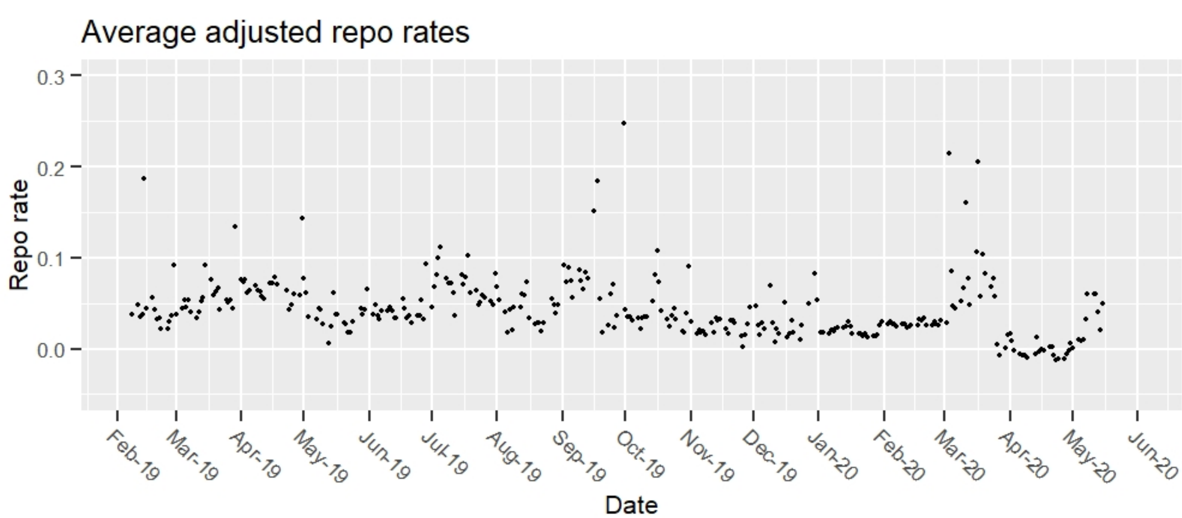


Figure 4: Percentage of cash initial margin This figure shows the percentage of cash initial margin across all main currencies and accounted for by each clearing service in our sample. The CDS and Futures and Options (FAO) services are part of ICE Clear Europe, while the remaining services are part of LCH Limited The time period is from February 2019 to June 2020.

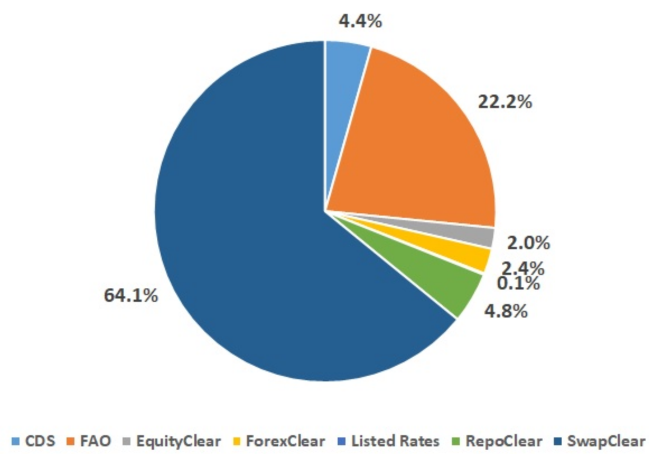


Figure 5: Initial margin and collateral ratio This figure shows the time series of the aggregate cash initial margin across UK CCPs and cash collateral ratio. The cash initial margin (converted to GBP) is paid in the three major currencies: USD, EUR, and GBP. The cash collateral ratio is the percentage of the initial margin paid in cash across all three currencies. The time period is from February 2019 to June 2020.

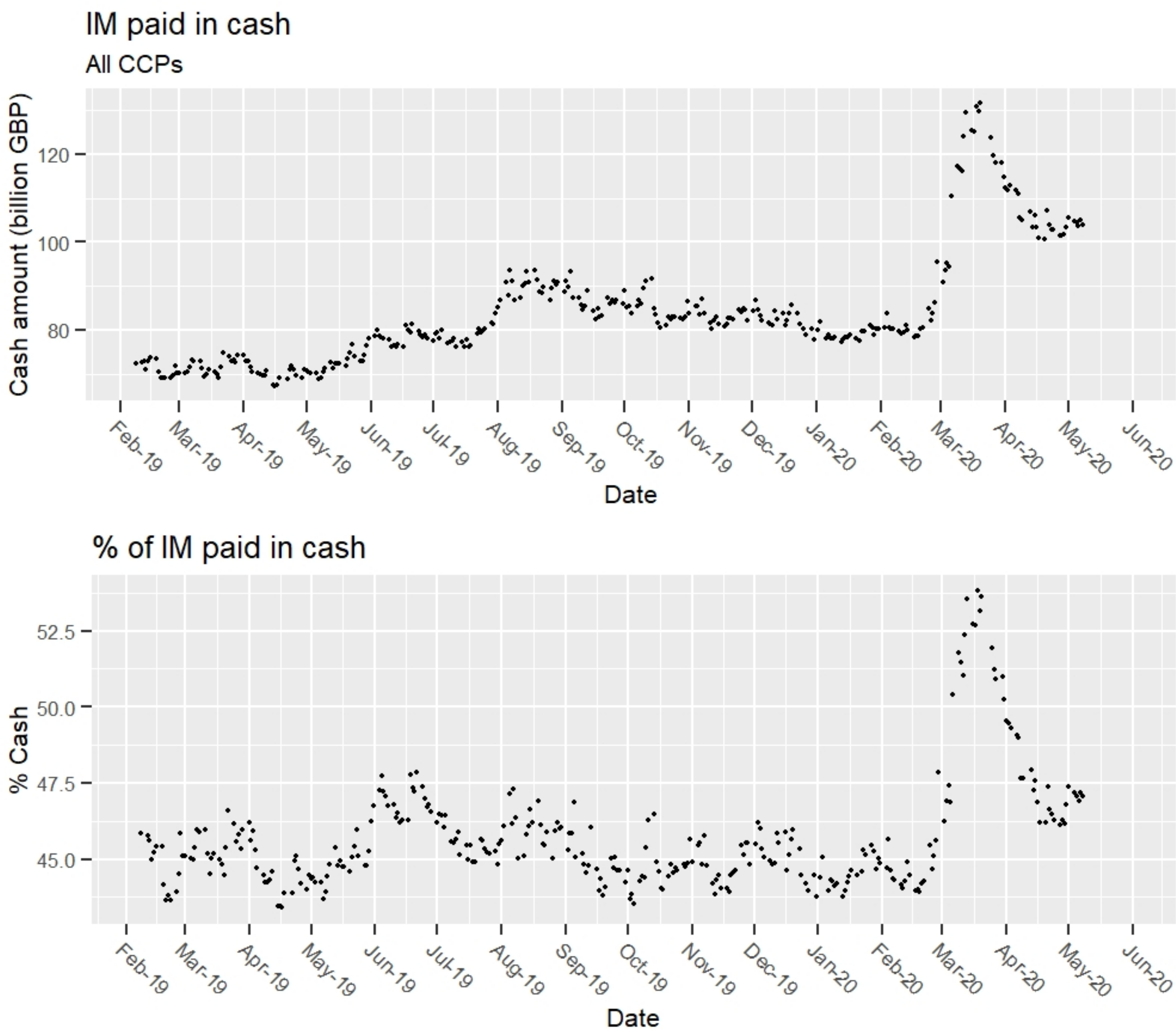


Figure 6: Initial margin and repo volume This figure shows the time series of the aggregate cash margin paid across UK CCPs, CCP reverse repo volumes, and CCP bond investments in the three major currencies (USD, EUR, and GBP). All currencies are converted to GBP to facilitate aggregation. The time period is from February 2019 to June 2020.

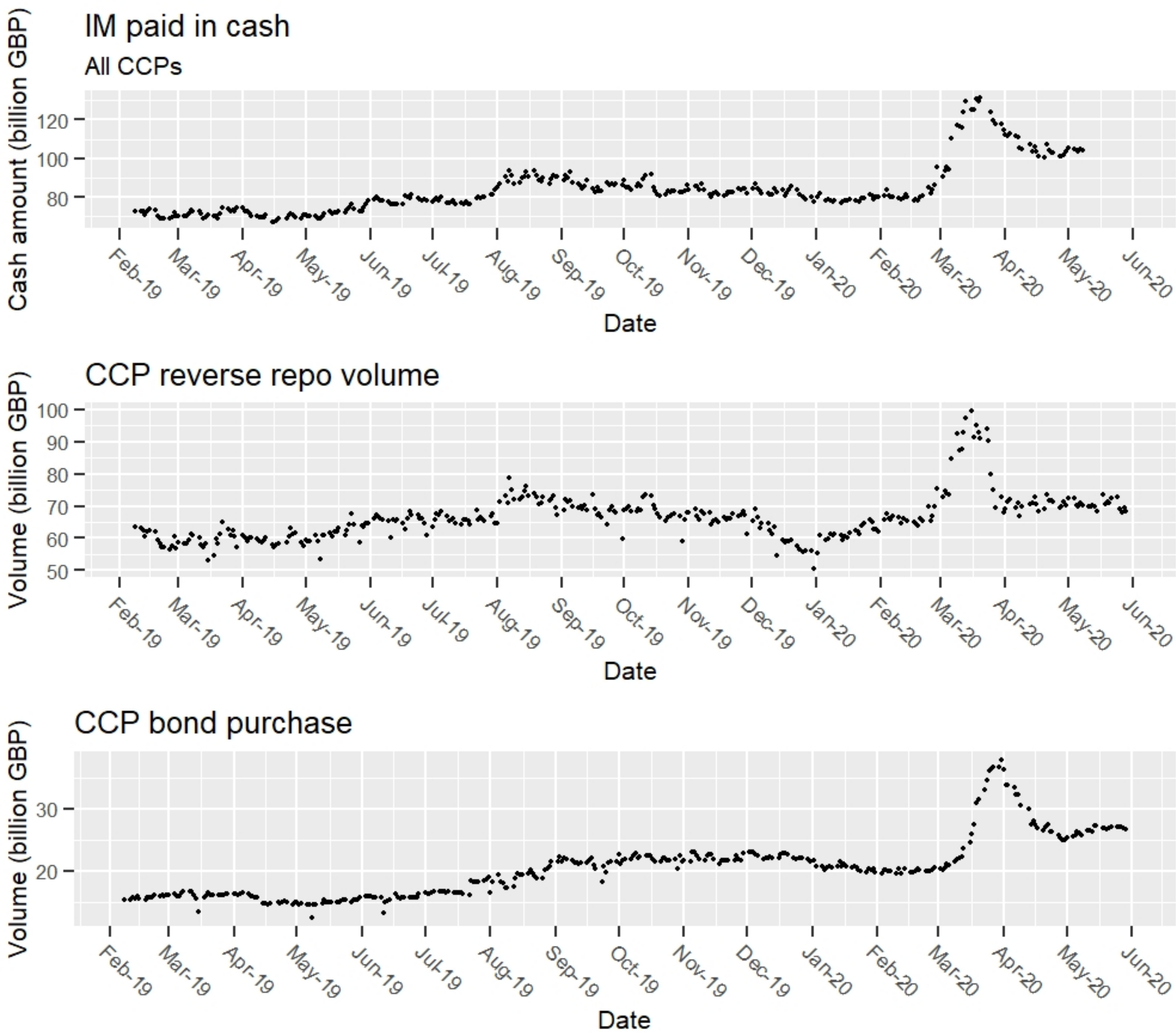


Figure 7: EUR Repo migration: Daily trading volumes (in GBP billion, top chart) and number of trades (bottom chart) for EUR-denominated repos cleared by the RepoClear service of LCH. The vertical dotted red line corresponds to February 19, 2023. The time period is from February 2019 to June 2020.

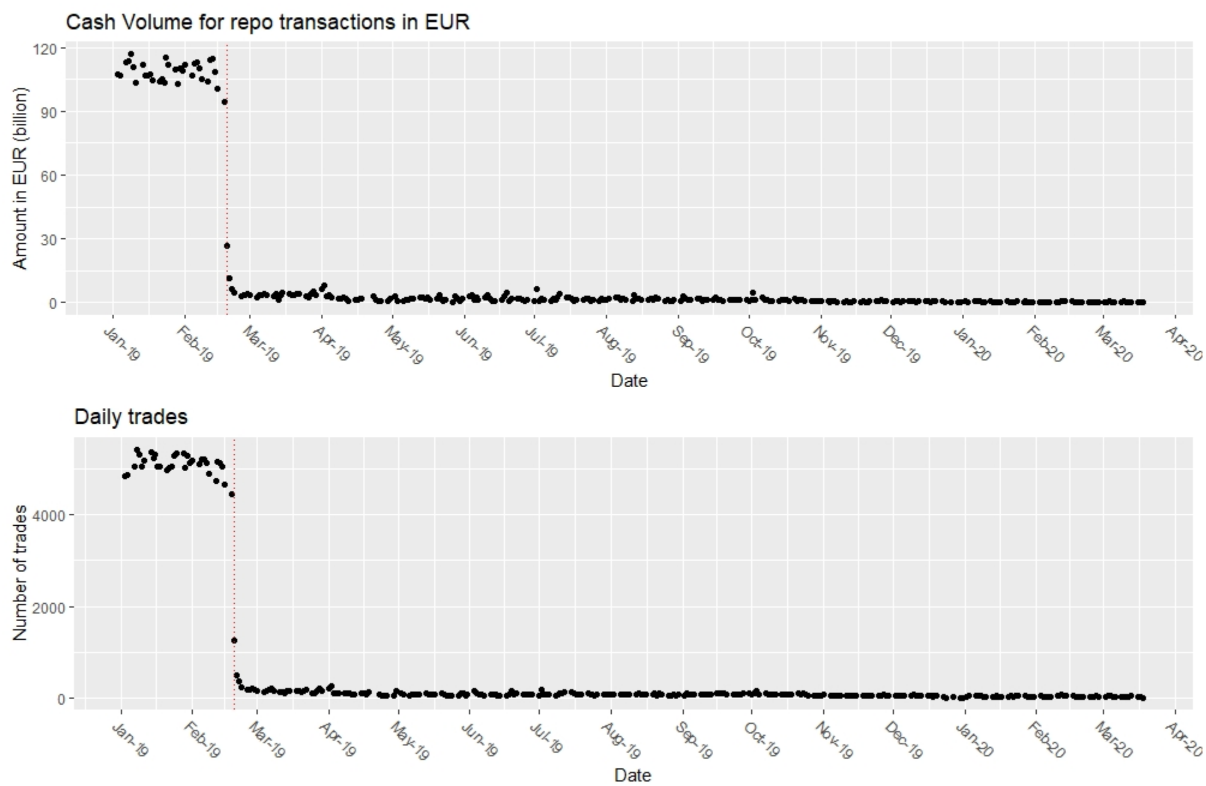


Table 1: Summary statistic This table shows the summary statistics of the variables used in the empirical analysis. The statistics are reported separately for each currency in which they are denominated. Note that all values expressed in currency units have been converted to GBP at the prevailing market exchange rate. $CashIM$ and $SecIM$ are the daily amounts of initial margin in cash and securities, respectively, pledged by all clearing members of the two CCPs in our sample. $CashIM(\%)$ is the percentage of cash over total initial margin. $VlmRR$ is the aggregate daily volume of reverse repo activity by the CCPs in our sample, and *Bonds* is the daily value of their investments in government bonds. *Repo* is the daily overnight general collateral repo rate. *Reserves* are the daily values of central bank reserves balances in each currency, and VIX is the implied volatility of broad equity market indices in the US, UK, and Eurozone. The sample time period is from February 2019 to June 2020.

		EUR				**GBP**				**USD**			
	Units	*mean*	*sd*	*min*	*max*	*mean*	*sd*	*min*	*max*	*mean*	*sd*	*min*	*max*
A. CCP collateral													
CashIM	GBP bn	24.02	6.14	17.21	39.12	21.19	6.15	14.07	39.28	43.14	7.25	33.57	72.89
SecIM	GBP bn	39.57	4.00	32.91	46.43	18.09	1.90	15.07	22.65	41.46	4.11	33.39	51.89
CashIM(%)	%	36.21	2.95	32.22	45.32	51.28	2.64	45.23	60.58	50.19	2.68	45.33	59.37
B. CCP Investments													
VlmRR	GBP bn	13.79	1.88	7.75	17.83	21.48	3.20	15.33	35.92	31.22	4.33	24.18	51.40
Bonds	GBP bn	3.51	0.87	2.43	6.25	2.17	1.04	0.61	3.94	14.87	3.57	8.82	30.71
C. Other variables													
Repo	%	-0.47	0.04	-0.56	-0.40	0.69	0.22	0.02	0.95	1.78	0.81	0.01	5.25
Reserves	GBP bn	2249.96	137.86	2009.31	2595.66	498.16	42.51	460.13	627.40	2276.25	641.72	1717.24	3978.64
VIX		19.61	13.63	10.60	85.60	18.32	11.99	9.63	69.73	20.40	13.29	11.54	82.69

Table 2: Cash Margin procyclicality This table shows the estimation results for specification (1). $CashIM$ is the daily aggregate amount of cash collateral pledged with all UK CCPs in each currency. *Repo* is the overnight repo rate for each currency. VIX is the implied volatility index associated with a broad stock market index for each currency. *Covid* is a dummy that equals one from February 19, 2020, when market volatility increased as a result of the COVID-19 pandemic. Δ indicates that the variable is taken in differences. The sample time period is from February 2019 to June 2020. Robust p-values are in parentheses. *, ** and *** denote significance at 10%, 5%, and 1% levels, respectively.

	$CashIM_t$				
	(1)	(2)	(3)	(4)	(5)
$\Delta Repo_{t-1}$			0.3800**	0.1664**	-0.9158**
			(0.019)	(0.015)	(0.041)
$Covid_t$				1.1599**	
				(0.028)	
VIX_{t-1}	0.4035**	0.0378	0.0386		0.0398
	(0.023)	(0.132)	(0.135)		(0.152)
$\Delta Repo_{t-1} \times Covid_t$				2.2083	
				(0.166)	
$\Delta Repo_{t-1} \times VIX_{t-1}$					0.0708**
					(0.045)
cons	21.1626***	1.9442	2.0079	2.1004**	1.9085*
	(0.003)	(0.113)	(0.102)	(0.016)	(0.096)
R^2	0.722	0.948	0.946	0.954	0.947
N	944	944	918	952	918
Lagged dep. var.	No	Yes	Yes	Yes	Yes

Table 3: Procyclicality in cash margin shares. This table shows the estimation results for model (2). $CashIM(\%)$ is the ratio (in %) of cash collateral over total collateral (cash plus securities) pledged with all UK CCPs in each currency. $CurrIM(\%)$ is the ratio (in %) of cash collateral pledged in a given currency over total cash collateral pledged in all currencies. *Repo* is the overnight repo rate for each currency. VIX is the implied volatility index associated with a broad stock market index for each currency. *Covid* is a dummy that equals one from February 19, 2020, when market volatility increased as a result of the COVID-19 pandemic. Δ indicates that the variable is taken in differences. The sample time period is from February 2019 to June 2020. Robust p-values are in parentheses. *, **, and *** denote significance at 10%, 5%, and 1% levels, respectively.

	$CashIM(\%)_t$					
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta Repo_{t-1}$	0.2712**	0.2707**	0.2861***	0.3037***	0.2852***	0.1170
	(0.018)	(0.020)	(0.010)	(0.004)	(0.002)	(0.152)
$\Delta Reserves_{t-1}$		-0.0002				
		(0.694)				
$Covid_t$			0.3014*		0.3015*	
			(0.067)		(0.067)	
VIX_{t-1}				0.0113*		0.0116**
				(0.058)		(0.044)
$\Delta Repo_{t-1} \times Covid_t$					0.0116	
					(0.966)	
$\Delta Repo_{t-1} \times VIX_{t-1}$						0.0102
						(0.126)
cons	1.8815	1.8930	2.6787**	3.2193**	2.6780**	3.2006**
	(0.138)	(0.128)	(0.011)	(0.012)	(0.012)	(0.012)
R^2	0.901	0.901	0.903	0.897	0.903	0.897
N	910	907	910	899	910	899
Lagged dep. var.	Yes	Yes	Yes	Yes	Yes	Yes

Table 4: Clearing member analysis Panel A shows summary statistics of our clearing-member variables. *CashIM* is the cash pledged by each clearing member with all UK CCPs. *ON_Repo_Borrowing* (*ON_Repo_Lending*) is the daily borrowing (lending) volume of each clearing member in the centrally cleared Sterling overnight repo market. *Repo* is the volume-weighted average overnight borrowing repo rate of each clearing member. *CDS* is the daily CDS spread for those clearing members with a CDS contract traded in their name. Panels B and C show the estimation results for specifications (3) and (4), respectively. Δ indicates that the variable is taken in differences. The sample time period is from February 2019 to June 2020. Robust p-values are in parentheses. *, **, and *** denote significance at 10%, 5%, and 1% levels, respectively.

Panel A	Units	*mean*	*sd*	*min*	*max*
CashIM	GBP bn	0.43	0.72	0.00	5.00
ON_Repo_Borrowing	GBP bn	1.32	1.72	0.00	17.99
ON_Repo_Lending	GBP bn	1.31	1.73	0.00	16.56
Repo	%	0.66	0.20	0.00	0.99
CDS	bps	57.87	27.39	15.89	221.53

Panel B		$CashIM_{jt}$	
	(1)	(2)	(3)
VIX_{t-1}	0.0003**		0.0004*
	(0.013)		(0.093)
$ON\_Repo\_Borrowing_{jt-1}$		0.0079*	0.0078*
		(0.076)	(0.082)
$ON\_Repo\_Lending_{jt-1}$		-0.0015**	-0.0015**
		(0.012)	(0.018)
$CashIM_{jt-1}$	0.9426***	0.9348***	0.9285***
	(0.000)	(0.000)	(0.000)
cons	0.0198***	0.0223*	0.0181
	(0.001)	(0.099)	(0.156)
R^2	0.889	0.866	0.866
N	7689	5393	5372

Panel C		$Repo_{jt}$	
	(1)	(2)	(3)
ΔCDS_{jt-1}	0.0012***		0.0012***
	(0.001)		(0.001)
$ON\_Repo\_Borrowing_{jt}$		0.0003	0.0026**
		(0.818)	(0.013)
$ON\_Repo\_Lending_{jt}$		-0.0044***	-0.0034***
		(0.006)	(0.002)
$Repo_{jt-1}$	0.9751***	0.9707***	0.9764***
	(0.000)	(0.000)	(0.000)
cons	0.0162***	0.0225***	0.0167***
	(0.001)	(0.000)	(0.000)
R^2	0.923	0.903	0.922
N	4877	5838	4506

Table 5: Cash margin and CCP reverse repo activity This table shows the estimation results for specification (5). $VlmRR$ is the daily amount of reverse repo volume executed by all UK CCPs in each currency. $CashIM$ is the absolute amount (stock) of cash pledged with all UK CCPs in each currency. $Covid$ is a dummy that equals one from February 19, 2020, when market volatility increased as a result of the COVID-19 pandemic. VIX is the implied volatility index associated with a broad stock market index for each currency. Δ indicates that the variable is taken in differences. The sample time period is from February 2019 to June 2020. Robust p-values are in parentheses. *, **, and *** denote significance at 10%, 5%, and 1% levels, respectively.

	$VlmRR_{it}$			$\Delta Bonds_{it}$		
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta CashIM_{it-1}$	0.4971**	0.4672*	0.4476*	0.0464	0.0461	0.0448
	(0.038)	(0.055)	(0.056)	(0.119)	(0.121)	(0.123)
$\Delta CashIM_{it-2}$	0.5780**	0.5298**	0.4726**	0.0163*	0.0159*	0.0148*
	(0.022)	(0.042)	(0.036)	(0.086)	(0.090)	(0.090)
$\Delta CashIM_{it-3}$	0.5806**	0.5206**	0.4452**	0.0272	0.0267	0.0250
	(0.021)	(0.040)	(0.031)	(0.163)	(0.171)	(0.171)
$\Delta CashIM_{it-4}$	0.5751**	0.5008*	0.4056*	0.0433*	0.0426*	0.0416*
	(0.020)	(0.050)	(0.055)	(0.092)	(0.096)	(0.084)
$\Delta CashIM_{it-5}$	0.4326**	0.3726*	0.2848*	0.0232**	0.0227**	0.0221**
	(0.037)	(0.066)	(0.067)	(0.028)	(0.031)	(0.020)
$Covid_t$		2.9731*			0.0283	
		(0.095)			(0.153)	
VIX_{t-1}			0.1257			0.0028
			(0.163)			(0.272)
cons	22.0855***	21.4315***	19.7762***	0.0087*	0.0024	-0.0462
	(0.000)	(0.000)	(0.003)	(0.059)	(0.671)	(0.353)
R^2	0.141	0.278	0.373	0.048	0.049	0.057
N	978	978	897	975	975	897
F-statistics	37.19	19.14	20.33	8.72	8.32	8.94
p-values	0.026	0.049	0.046	0.098	0.100	0.096

Table 6: Cash collateral counter-cyclical effects This table shows the estimation results for specification (6). All variables are currency-specific and on a daily frequency. *Repo* is the ON repo rate. $VlmRR$ is the daily amount of reverse repo volume executed by all UK CCPs. *Bonds* is the outstanding amount of government bond investments by CCPs. *Reserves* is the aggregate amount of central bank reserves balances. VIX is the implied volatility index associated with a broad stock market index. Δ indicates that the variable is taken in differences. The sample time period is from February 2019 to June 2020. Robust p-values are in parentheses. *, ** and *** denote significance at 10%, 5%, and 1% levels, respectively.

					$Repo_{it}$				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$VlmRR_{it-1}$	-0.0020*		-0.0017			0.0014	0.0014	0.0094	0.0017
	(0.053)		(0.118)			(0.727)	(0.728)	(0.177)	(0.695)
$\Delta Bonds_{it-1}$		-0.0137***	-0.0112**			-0.0102**	-0.0100**	-0.0013	0.0003
		(0.005)	(0.032)			(0.021)	(0.019)	(0.511)	(0.806)
$\Delta Reserves_{it-1}$				-0.0001*		-0.0001**	-0.0002	-0.0000*	-0.0001***
				(0.085)		(0.013)	(0.463)	(0.063)	(0.003)
VIX_{it-1}					-0.0016	-0.0018	-0.0018	0.0018	-0.0018
					(0.383)	(0.486)	(0.489)	(0.190)	(0.490)
$VIX_{it-1} \times \Delta Reserves_{it-1}$							0.0000		
							(0.590)		
$VIX_{it-1} \times \Delta VlmRR_{it-1}$								-0.0002**	
								(0.050)	
$VIX_{it-1} \times \Delta Bonds_{it-1}$									-0.0004**
									(0.029)
cons	0.0651**	0.0203**	0.0593**	0.0210**	0.0688	0.0424	0.0424	-0.1007	0.0374
	(0.022)	(0.012)	(0.048)	(0.013)	(0.242)	(0.182)	(0.179)	(0.284)	(0.259)
R^2	0.917	0.916	0.916	0.915	0.918	0.917	0.917	0.919	0.917
N	957	950	950	952	926	914	914	914	914
Lagged Repo rate	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 7: Initial Margin (IM) statistics around the migration of EUR-denominated repo contracts on Fberuary 19, 2019. The table shows daily average values (in GBP billion) for IM requested and cash IM paid to the RepoClear service of LCH, as well as cash IM paid to all the clearing services in our sample. The top panel shows numbers for EUR-denominated IM and the bottom panel shows averages for GBP and USD-denominated IM. The "Before" period includes the dates of February 8 to February 18 whereas the "After" period includes the dates of February 19 to March 4, 2019. *, ** and *** denote significance at 10%, 5%, and 1% levels, respectively of a Welch t-statistic of mean equality.

	RepoClear		All CCPs
EUR	IM requested	Cash IM paid	Cash IM paid
Before	7.54	2.89	19.21
After	5.42	2.49	17.64
Difference	−2.11***	−0.40***	−1.57***
GBP, USD	IM requested	Cash IM paid	Cash IM paid
Before	11.1	2.3	53.5
After	10.8	1.9	52.2
Difference	-0.12	−0.16***	−0.65**

Table 8: EUR repo migration effects. This table shows estimation results of models (7) and (8). *Event* is a dummy variable that takes the value of 1 after February 19, 2019 and 0 before that and EUR is a dummy variable that takes the value of 1 for EUR and 0 for USD and GBP. The models are estimated over the period between February 8 and March 4, 2019, approximately 10 ten days before and after the EUR repo migration. For both models we use currency fixed effects and standard errors are clustered by currency. *, ** and *** denote significance at 10%, 5%, and 1% levels respectively.

	$CashIM_{it}$	$CashIM(\%)_{it}$
$CashIM_{it-1}$	0.6563***	
	(0.001)	
$CashIM(\%)_{it-1}$		0.7299***
		(0.002)
$\Delta Repo_{it-1}$	-0.0299	0.4979
	(0.951)	(0.651)
$Event_t$	-0.4417*	-0.3348
	(0.084)	(0.349)
$Event_t \times EUR_i \times \Delta Repo_{it-1}$	-9.8311	-48.4787*
	(0.112)	(0.092)
$\Delta Reserves_{it-1}$		0.0035
		(0.704)
$cons$	8.3753***	12.1452**
	(0.003)	(0.014)
R^2	0.733	0.810
N	45	45

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