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The cost of clearing fragmentation

Evangelos Benos,[(1)] Wenqian Huang,[(2)] Albert Menkveld[(3)] and Michalis Vasios[(4)]

Abstract

Fragmenting clearing across multiple central counter-parties (CCPs) is costly. This is because dealers providing liquidity globally, cannot net trades cleared in different CCPs and this increases their collateral costs. These costs are then passed on to their clients through price distortions which take the form of a price differential (basis) when the same products are cleared in different CCPs. Using proprietary data, we document an economically significant CCP basis for dollar swap contracts cleared both at the Chicago Mercantile Exchange (CME) and the London Clearing House (LCH) and provide empirical evidence consistent with a collateral cost explanation of this basis.

Key words: Central clearing, CCP basis, collateral, fragmentation.

JEL classification: G10, G12, G14.

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1 Introduction

A key element of the G-20 post-financial crisis derivatives reform agenda, has been the mandate for centralized clearing of a wide range of OTC-traded derivatives. This has generated considerable policy and academic discussion on the optimal shape and form of clearing arrangements. Much of this discussion has centered around the netting opportunities associated with various clearing arrangements and the potential to economize on collateral (e.g. Singh (2009), Singh (2013), Sidanius and Zikes (2012)). In this respect, there appears to be consensus that, given a certain amount of central clearing, it is optimal, from a collateral-saving perspective, to concentrate activity in just one CCP (Duffie and Zhu (2011)). In reality however, clearing is fragmented with multiple clearing houses operating within and across jurisdictions, often clearing the same or similar derivatives contracts. Examples include U.S. dollar (USD) interest rate swap (IRS) contracts being cleared in both the Chicago Mercantile Exchange (CME) and LCH in London, euro swaps being cleared in LCH and Eurex Exchange in Frankfurt and Japanese yen (JPY) contracts being cleared in LCH and the Japan Securities Clearing Corporation (JSCC). What the implications of this fragmentation in the clearing landscape are, is an open and policy-relevant question.

This paper sheds light on this question by providing direct evidence of the costs associated with fragmentation in clearing. In doing this, we theoretically argue, and empirically document, that fragmentation in clearing gives rise to economically significant price distortions, which become visible when the same contracts are cleared by different CCPs. These distortions reflect dealers' collateral costs and represent a real cost to market end-users.

In particular, we document that USD-denominated swap contracts, cleared in CME, trade at a premium relative to the exact same contracts cleared in LCH. This price differential - termed here the CME-LCH basis - is economically significant. For instance, during our sample period, it fluctuates on average (across maturities) between one and 3.5 basis points (bps). This is substantial given that outstanding notional amounts in the USD swap market were, at the time, around $100 trillion and daily client trading volumes around $50 billion.[1] Such price differentials are not unique to CME and LCH. They exist among many contracts being cleared in multiple CCPs and have been known for some time to market practitioners.[2] However, to our knowledge, they have not been previously formally studied.

As such, we first provide a formal explanation for the CCP basis using a variation of the dynamic inventory management model presented in Foucault et al. (2013). The intuition as to why the basis arises is as follows: Due to the global nature of OTC derivatives markets, major dealers act as liquidity providers across jurisdictions, meaning that their client trades are cleared in multiple CCPs. This is especially true if clients in a particular jurisdiction only tend to access their local CCP either because they are mandated to do so or because they lack the financial resources to access overseas CCPs. Thus, the netting opportunities for dealers' overall portfolios are reduced. For example, a dealer selling a USD swap contract to a US client and simultaneously buying the same contract from a European client, cannot offset these two exposures if the two trades are cleared separately in CME and LCH respectively. This reduction in netting opportunities increases dealers' collateral requirement as they are forced to pledge collateral with each CCP. More generally, the more imbalanced dealers' inventories in each CCP are, the more collateral they will need to pledge. Such imbalances will typically fluctuate over time but will persist when dealers' client flows, in different CCPs, are consistently directional.[3]

This increased collateral requirement then represents for dealers an unavoidable, if variable, cost. Collateral is costly to dealers not only because it needs to be funded by tapping debt and equity markets but also because of debt overhang (Andersen et al. (2019)).

[1]For detailed information on aggregate outstanding notional amounts, in various OTC derivatives, see https://stats.bis.org/statx/srs/table/d5.1?p=20152&c=.

[2]See for example the relevant statistics reported by Clarus Financial Technology: https://www.clarusft.com/ccp-basis-and-volume-in-major-currencies/.

[3]This appears to be the case for example in the U.S. where anecdotal evidence suggests that banks issuing long-term fixed-rate mortgages hedge this exposure in the local USD swap market thus creating a permanent buy flow for dollar swaps that are cleared on CME.

To the extent that collateral is funded by liabilities (debt or equity) that have lower seniority than existing debt, it renders the latter safer and therefore increases its market value at the expense of existing shareholders.

Therefore, to compensate for these costs, dealers may quote higher (lower) prices, where they are faced with buy (sell) client flow, than they would if all client flow was concentrated in one CCP and netting opportunities were maximized. Importantly, while this effect may be present in any contracts that are part of the same netting set, it becomes clearly visible when the exact same contract is cleared in two different CCPs. In this case, it manifests itself as a price differential, for the contract, across the two CCPs. Furthermore, this differential cannot be arbitraged away by simultaneously buying in the CCP where the price is low and selling where it is high, because these two trades would be subject to collateral requirements and therefore would be costly to execute. The same argument also partially explains why market participants (whether these are dealers or their clients) may not execute their trades where prices are more favorable. Since most market participants' portfolios typically consist of both long and short positions, in contracts belonging to the same netting set, to exploit the CCP price differential they would have to split the long and short positions of their portfolios across jurisdictions, which would attract additional collateral. Market participants have therefore a strong incentive to clear all their trades in one CCP and minimize their collateral cost, despite having to bear the associated CCP basis cost. This is in addition to regulatory or other economic constraints that force some (primarily smaller) market participants to clear locally.

Overall, our intuition is very similar to that of Ho and Stoll (1981) and Hendershott and Menkveld (2014) where risk-averse dealers adjust their mid-quotes to create an imbalance in client flow that reduces their inventory and thus their overall risk exposure. Our model is only different in that dealers manage two inventories (one for each CCP) instead of one, and that, being risk neutral, their only cost stems from the required collateral that they need to pledge with the CCPs.

Our model gives rise to a number of testable hypotheses regarding the CME-LCH basis for USD swaps.

- First, since the CME-LCH basis allows dealers to recoup their collateral costs, our model predicts that it will respond positively to the amount of collateral pledged by swap dealers.

- Second, the basis will be lower in the presence of more sophisticated clients who are flexible to choose where to clear their trades. Whenever these clients happen to be otherwise indifferent as to where to clear (e.g. because of no netting advantages), they will clear in the CCP where dealers quote the better price. Thus, these clients' trades will likely be reducing dealers' local inventory imbalances and therefore the observed CCP basis.

- Third, the CME-LCH basis should respond positively to changes in dealers' credit risk. The higher a dealer's riskiness, the more severe the debt overhang and the higher the compensation that equity holders will demand via the CME-LCH basis.

- Finally, since dealers recoup their collateral costs by quoting a higher price for dollars swaps on CME and a lower one on LCH, we would expect that client buy (sell) flow in USD swaps on LCH (CME), would lead to a decrease of the CME-LCH basis.

We test these hypotheses using proprietary data from LCH's SwapClear service, from January 2014 to end June 2016. The data includes transactions in all products that are part of the SwapClear netting set, namely interest rate swaps (IRSs), forward rate agreements (FRAs) and overnight index swaps (OISs), in the major currencies (USD, euro, and GBP). An important feature of our data is that it identifies counterparties, which allows us to isolate dealers' and clients' activity and also identify non-dealer banks who can flexibly clear their contracts in the CCP of their choosing. Finally, our data also includes the amounts of own collateral pledged, by participating dealers, with LCH's SwapClear service.

We estimate time series and dealer panel specifications, as well as a vector autoregression (VARX) model, to examine dynamic inter-relationships between our variables of interest. We find broad support in the data for the hypotheses implied by our model. Dealers' amount of pledged collateral, along with dealer credit spreads, correlate positively and significantly with the CME-LCH basis whereas the proportion of trading volume in SwapClear products executed by non-dealer banks correlates negatively and significantly, consistent with the idea that the basis arises because of local dealer inventory imbalances, which location-flexible clients help to reduce. Corroborating this, the VARX specification results show that an increase in client net (i.e. buy minus sell) volume in USD IRS contracts on LCH, where they are traded at a discount, leads to a decrease in the CME-LCH basis.

More generally, our paper demonstrates the importance, for asset pricing, of back-office processes and institutional features, usually referred to as the "post-trade cycle". This includes both clearing and transaction settlement both of which are particularly sensitive to technological and regulatory innovations.

The paper proceeds as follows: In the next section we briefly describe the related literature, in Section 3 we provide details on the institutional framework of centralized clearing, in Section 4 we present our model and in Section 5 we describe the data, the empirical specifications and present the results. All proofs related to the model, are included in the Appendix.

2 Literature Review

This paper is closely related to the literature on the role of collateral, especially in the context of central clearing. Duffie and Zhu (2011) compare the netting benefits between bilateral clearing, where exposures across assets with any one counterparty can be netted, and central clearing, where exposures across counterparties in only one asset class can be netted. The authors show that, to achieve the maximum netting benefits with central clearing, it is optimal to have one CCP in one asset class. Menkveld (2017) extends their framework by adding tail risk. He uses this extended framework to identify crowding in clearing member positions as an "overlooked" risk for CCPs. Garratt and Zimmerman (2018) extend the Duffie and Zhu (2011) methodology to more realistic financial networks for which they obtain exact conditions under which central clearing alters the expectation and variance of exposures. These authors also conclude that once clearing is introduced, it is optimal to novate all exposures via a single CCP.

Duffie et al. (2015) empirically estimate the impact of central clearing on collateral demand. Based on bilateral exposure data in credit default swaps (CDS), the authors find that central clearing can lower overall collateral demand when there is no substantial clearing fragmentation. Corroborating this literature, our paper is the first to empirically document how fragmentation in clearing, and the associated break up of netting sets, increases collateral costs and distorts asset prices by giving rise to a CCP basis.

Our paper also contributes to the literature on dynamic inventory management. Our setup is similar to Ho and Stoll (1981) and Foucault et al. (2013) who analyze dealers' optimal dynamic trading strategies in the presence of inventory holding costs.[4] Our paper differs in that dealers are risk neutral, so that inventory risk is not a concern to them, but are faced with inventory holding costs, in the form of collateral, which are a function of inventory size. These collateral costs result from fragmentation in contract clearing as discussed above. As such, our paper is the first in the literature to model dealers' dynamic inventory management in a fragmented clearing landscape.

Our paper also provides new evidence on the asset pricing implications of dealers' inventory holding costs. Garleanu and Pedersen (2011) provide theoretical foundations by studying the asset pricing implications of margin constraints. Their margin-based CAPM

[4] Some of the classic papers in this literature also include: Garman (1976), Stoll (1978), Amihud and Mendelson (1980), Hasbrouck (1988) and Grossman and Miller (1988).

predicts that there should be price differences between securities with identical cash-flows but different margins. There is also evidence that indeed dealers price in their inventory holding costs in various markets such as equities (see e.g. Naik and Yadav, 2003; Hendershott and Menkveld, 2014), US Treasuries (see e.g. Fleming and Rosenberg, 2008), and corporate bonds (see e.g. Randall, 2015; Schultz, 2017; Friewald and Nagler, 2018).

More recently, there has been additional evidence of price effects in derivatives and foreign exchange markets, as a result of dealers' balance sheets being influenced by regulation. Andersen et al. (2019) articulate how, in the presence of debt overhang, the posting of collateral results in funding value adjustments that dealers charge in interest rate swap markets. Debt overhang is a result of increased credit risk among dealers in the post-crisis period, which in turn is caused by new, bail-in rules on bank resolution and a resulting perception that institutions are no longer "too-big-to-fail". Du et al. (2018) show that constraints on banks' balanced sheets induced by capital regulation play a role in sustaining deviations from the Covered Interest Parity (CIP). Klinger and Sundaresan (2019) and Boyarchenko et al. (2018) attribute to the same cause the fact that swap spreads have been low since the financial crisis and have recently turned negative for some contract maturities. Cenedese et al. (2019) show that swap contracts that are bilaterally cleared, trade at a premium, relative to centrally cleared ones, due to higher regulatory costs (e.g., higher risk weights) that are passed on to market prices via the so-called valuation adjustments (XVA) and Ranaldo et al. (2019) show that prices for European repos drop, during quarterly reporting periods, when Basel III leverage ratio requirements constrain banks' repo borrowing demand the most. Additionally, recent evidence also suggests that dealers' balance sheet constraints can affect their trading activity and can lead them to ration their balance sheet capacity. For instance, Kotidis and van Horen (2018) document reduced Sterling repo dealer volumes and Benos and Zikes (2018) reduced gilt inter-dealer volumes as a result of capacity constraints in dealers' balance sheets induced by regulation and elevated funding costs respectively. Similarly, Acosta-Smith et al. (2018) find that balance sheet constrained dealers, acting as clearing members of CCPs, reduce the number of new clearing clients and also reduce the number of transactions that they clear for their existing clients. Overall, our results corroborate this literature and show that dealers' inventory holding costs also depend on the shape and form of clearing arrangements.

3 Institutional Framework

3.1 Central clearing

Although clearing houses (or central counterparties - CCPs) have existed for a long time, they only recently emerged as an important pillar of the regulation for the financial system.[5] In 2009, G20 Leaders laid down central clearing requirements for standardized OTC derivatives as part of their broader agenda for making financial markets safer. This has rendered CCPs systemically important entities in the post-crisis financial market landscape.

CCPs intermediate between the counterparties of a bilateral trade and become the buyer of the original seller, and the seller of the original buyer. By converting the bilateral exposures to exposures against the CCP, the original parties protect themselves against counterparty risk, i.e. the risk of losses due to counterparty default.

The reduction in counterparty risk comes at a cost, as CCPs require clearing members to post collateral, mostly initial margin, daily, or sometimes even intra-day, to cover potential losses in the event of a clearing member default.[6] CCPs calculate initial margin using risk-based models, such as Value-at-Risk (VaR) or Standard Portfolio Analysis of Risk (SPAN). The calculated values of initial margin are a function of the riskiness and size of a given

[5] One of the first U.S. clearing houses was the New York Clearing House, which was founded in 1853 to streamline the clearing and settling of checks.

[6] Clearing members are also required to make default fund contributions, which contribute towards the CCP's mutualized loss sharing arrangements. However, default fund contributions account for only a fraction (e.g., 5-6%) of the total funds available to the CCP in the event of a default. An example of the breakdown of a CCP's clearing member default resources, the so-called default waterfall, can be found here: http://www.lch.com/documents/731485/762506/2_default_waterfall_ltd_0.35_150529/.

portfolio. Margined portfolios may include contracts of various currencies and maturities and even contracts of different, but related, products. This means that any offsetting exposures in these contracts are netted prior to being margined and the contracts for which this is possible constitute a netting set. For example, LCH's SwapClear service includes IRS, FRA and OIS contracts in the same netting set. However, any positions in different services within the same CCP (i.e. positions that are not in the same netting set) or any positions in the same contracts held in different CCPs cannot be netted.

The G20 objective for more central clearing has been implemented in U.S. and Europe through the Dodd-Frank Act and the European Market Infrastructure Regulation (EMIR; regulation No 648/2012), respectively. In the U.S., centralized clearing of certain standardized IRS contracts has been mandatory for U.S. persons since March 2013. The EMIR clearing obligation was phased-in in June 2016 and required European counterparties of certain OTC interest rate derivatives to clear their transactions through an authorized central counterparty. As a result of the clearing obligation, the centrally-cleared segment of interest rate derivatives dominates trading during our sample period.[7]

3.2 Clearing fragmentation in the IRS market

Clearing in the USD-denominated segment of the IRS market is dominated by two clearing houses, the London Clearing House (LCH) and the Chicago Mercantile Exchange Clearing (CME). LCH started clearing plain vanilla IRS, through its SwapClear platform, in 1999. It supports clearing in 18 currencies, some with tenors up to 50 years, while its services are used by almost 100 financial institutions from over 30 countries, including all major dealers. CME begun clearing over-the-counter IRS in 2010. Its product offering includes 19 currencies and has about 80 clearing members. During our sample period of January 2014 to June 2016, LCH accounted for approximately 55% of the USD IRS volume cleared

[7] For example, Cenedese et al. (2019) report that in 2015 90% of USD swap volumes and 85% of trades are centrally cleared.

by these two CCPs, with the rest being cleared by CME.

4 A model for the CCP basis

Our model is based on the inventory holding cost model in Foucault et al. (2013). A representative and competitive dealer makes markets for a single type of derivative contract (such as a plain vanilla fixed-to-floating IRS). There are infinite time periods. At each period t, a unit mass of liquidity traders would like to trade the contract. Crucially, the contract is mandated to be cleared in two different CCPs, meaning that a contract exposure in one CCP cannot be netted against a contract exposure in the other. The model details are as follows:

Asset: The derivative contract has an infinitely long maturity. The contract's underlying asset has a fundamental value μ_t (e.g. the fixed rate of an IRS contract), which follows a martingale process that is common knowledge:

$$\mu_t = \mu_{t-1} + \epsilon_t \quad \epsilon_t \sim (0, \sigma^2)$$

The contract is mandated to be cleared in two different CCPs (A and B) and in CCP i, the contract is quoted and traded at price p_t^i, which can be different from the fundamental value. Quoted prices are different depending on whether liquidity traders are buying or selling and the mid-quote m_t^i is defined as the average of the buy and sell quoted prices at time t. The time t mark-to-market value of the contract traded in CCP i, is the first difference of execution prices $(p_t^i - p_{t-1}^i)$, which represents the one-period gains or losses associated with that contract.

Liquidity traders: There is a unit mass of liquidity traders. A proportion δ of them are price-sensitive: they place a buy order in the CCP with the best price if $m_t^i < \mu_t$ and a sell order in the CCP with the best price if $m_t^i > \mu_t$ where i denotes the CCP with the best available price. If $m_t^A = m_t^B = \mu_t$, they do not trade. That is, price-sensitive liquidity traders have access to and can trade flexibly across both CCPs. The remaining $1 - \delta$ proportion of liquidity traders are equally split between CCPs A and B and are price-insensitive. This means that they always trade, regardless of price levels, and can only do so at their local CCP. In CCP A, a proportion π of them places a buy order and the remaining $1 - \pi$ places a sell order. The opposite occurs in CCP B where π of them place a sell order and $1 - \pi$ place a buy order. Hence, the price-insensitive buy-sell order flow is balanced across CCPs but not within each individual CCP. The net price-insensitive order flow in CCP A is $\frac{1}{2}(1-\delta)(2\pi - 1)$ and that in CCP B is $\frac{1}{2}(1-\delta)(1-2\pi)$. Lemma 1 in the Appendix summarizes the total (i.e. both price-sensitive and price-insensitive) expected flow $E[d_t^i]$ by liquidity traders in each CCP under all price configurations.[8]

Dealer: There is a representative and competitive dealer who is risk neutral and who always responds to liquidity traders' requests to trade. The dealer is active in both CCPs but crucially, she cannot net any offsetting exposures across CCPs. The end-of-period t dealer's position in CCP i is z_{t+1}^i and the dealer's total position across CCPs is $z_{t+1} = z_{t+1}^A + z_{t+1}^B$.[9] Being competitive, the dealer takes p_t^i as given and chooses the number of contracts q_t^i that she is willing to supply in each CCP at a given price.[10] Hence, after selling q_t^i contracts in CCP i, the dealer's inventory in that CCP, at the end of period t, is $z_{t+1}^i = z_t^i - q_t^i$. The position with each CCP attracts a collateral of $\sigma|z_{t+1}^i|$ where σ is the risk of the contract. The dealer must fund each unit of collateral at cost ϕ. This can be either interpreted as a direct cost or a debt overhang cost accruing to shareholders as in Andersen et al. (2019). Given that the dealer cannot net positions across CCPs, the total

[8]For tractability, we assume that liquidity traders do not bear collateral costs. In reality of course they do and, if anything, this would exacerbate the CCP basis as it would be costly to arbitrage it away.

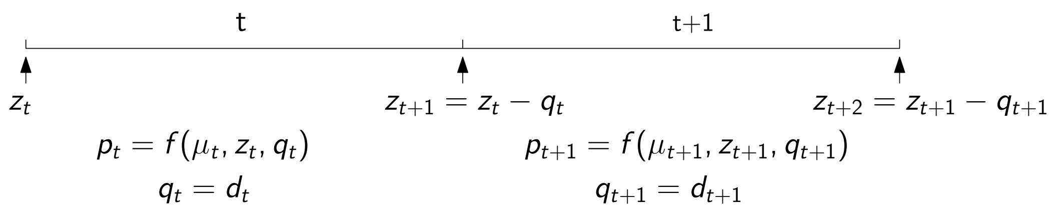
[9]The dealer has a long (short) position in CCP i when $z_t^i > 0$ ($z_t^i < 0$). In the case of IRS contracts, the dealer pays the fixed and receives the floating rate when $z_t^i > 0$.

[10]$q_t^i > 0$ ($q_t^i < 0$) means the dealer is selling (buying) swap contracts in CCP i at time t

collateral cost of the dealer across CCPs is:

$$\phi\sigma|z^A_{t+1}| + \phi\sigma|z^B_{t+1}|$$

Market clearing: Let d^i_t denote the total liquidity demand in CCP i. Markets clear in each CCP when $q^A_t = d^A_t$ and $q^B_t = d^B_t$. The key variables of the model along with the market clearing conditions are summarized in the time-line below:



The dealer's problem

At the end of time period t, the dealer's wealth is the sum of the mark-to-market values of her $t+1$ inventories in the two CCPs, minus the collateral cost associated with each inventory:

$$\begin{aligned}\omega_{t+1} = & \underbrace{(p^A_{t+1} - p^A_t)z^A_{t+1}}_{\text{Mark-to-market value of } z^A_{t+1}} + \underbrace{(p^B_{t+1} - p^B_t)z^B_{t+1}}_{\text{Mark-to-market value of } z^B_{t+1}} - \underbrace{\phi\sigma|z^A_{t+1}| - \phi\sigma|z^B_{t+1}|}_{\text{Total collateral cost}} \qquad (1)\\ =&(p^A_{t+1} - p^A_t)(z^A_t - q^A_t) + (p^B_{t+1} - p^B_t)(z^B_t - q^B_t) - \phi\sigma|z^A_t - q^A_t| - \phi\sigma|z^B_t - q^B_t|\end{aligned}$$

At time t the dealer maximizes, with respect to the quantity of contracts sold q^i_t, her next-period total wealth. Being risk-neutral, the dealer solves:

$$\max_{q^A_t, q^B_t} E[\omega_{t+1}] \qquad (2)$$

The first order conditions of this problem yield the relationship between current and expected execution prices:

$$
p_t^A = \begin{cases} E_t[p_{t+1}^A] + \phi\sigma, & \textit{if} \quad q_t^A > z_t^A \to z_{t+1}^A < 0 \\ E_t[p_{t+1}^A], & \textit{if} \quad q_t^A = z_t^A \to z_{t+1}^A = 0 \\ E_t[p_{t+1}^A] - \phi\sigma, & \textit{if} \quad q_t^A < z_t^A \to z_{t+1}^A > 0 \end{cases} \tag{3}
$$

$$
p_t^B = \begin{cases} E_t[p_{t+1}^B] + \phi\sigma, & \textit{if} \quad q_t^B > z_t^B \to z_{t+1}^B < 0 \\ E_t[p_{t+1}^B], & \textit{if} \quad q_t^B = z_t^B \to z_{t+1}^B = 0 \\ E_t[p_{t+1}^B] - \phi\sigma, & \textit{if} \quad q_t^B < z_t^B \to z_{t+1}^B > 0 \end{cases} \tag{4}
$$

Rational expectations equilibrium and the CCP basis

In the above setup, the representative dealer chooses the quantities q_t^i of contracts to be sold (or bought) in each CCP given current inventory levels z_t^i, prevailing execution prices p_t^i and the fundamental asset price μ_t. The total quantity of the contract being supplied feeds back into execution prices so that quantities and prices are jointly determined. Proposition 1 summarizes the equilibrium relationship between these variables in each CCP.

Proposition 1. ***Equilibrium price and inventory relationships in each CCP***

(i) Execution price equilibrium relationship

$$
\begin{bmatrix} p_t^A \\ p_t^B \end{bmatrix} = \begin{cases} \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\phi\sigma}{\delta} \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} z_{t+1}^A \\ z_{t+1}^B \end{bmatrix}, & \textit{if} \quad z_{t+1}^A z_{t+1}^B > 0 \\ \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\phi\sigma}{\delta} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} z_{t+1}^A \\ z_{t+1}^B \end{bmatrix}, & \textit{if} \quad z_{t+1}^A z_{t+1}^B = 0 \\ \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\phi\sigma}{\delta - |(1-\delta)(2\pi-1)|} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} z_{t+1}^A \\ z_{t+1}^B \end{bmatrix}, & \textit{if} \quad z_{t+1}^A z_{t+1}^B < 0 \end{cases} \tag{5}
$$

(ii) Mid-quote equilibrium relationship

$$
\begin{bmatrix} m_t^A \\ m_t^B \end{bmatrix} = \begin{cases} \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\phi\sigma}{\delta} \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} z_t^A \\ z_t^B \end{bmatrix}, & if \quad z_{t+1}^A z_{t+1}^B > 0 \\ \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\phi\sigma}{\delta} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} z_t^A \\ z_t^B \end{bmatrix}, & if \quad z_{t+1}^A z_{t+1}^B = 0 \\ \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\phi\sigma}{\delta - |(1-\delta)(2\pi-1)|} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} z_t^A \\ z_t^B \end{bmatrix}, & if \quad z_{t+1}^A z_{t+1}^B < 0 \end{cases} \tag{6}
$$

Proof. See the Appendix.

The above proposition suggests that when the dealer's inventories in two CCPs are in the same direction, i.e., $z_{t+1}^A z_{t+1}^B > 0$, the prices and mid-quotes in the two CCPs are both either higher or lower than the fundamental asset value μ depending whether the dealer wishes to induce buy or sell flow by liquidity traders in the two CCPs. Furthermore, the prices across CCPs both depend on the total amount of inventory $z_{t+1}^A + z_{t+1}^B$, rather than the local amount, and for this reason they are the same. This is because the marginal cost of collateral is constant i.e. independent of the total collateral amount. Similarly, when the dealer has zero inventory in at least one CCP, i.e., $z_{t+1}^A z_{t+1}^B = 0$, the price in that CCP equals the fundamental value μ as there is no need to induce liquidity trader flow.The price in the other CCP, however, will depend on the dealer's inventory there. Hence, prices and mid-quotes across CCPs will not be the same.

The most interesting case arises when the dealer has opposite exposures in the two CCPs. Suppose for example that $z_t^B < q_t^B = q_t^A < z_t^A$ so that $z_{t+1}^A > 0$ and $z_{t+1}^B < 0$ i.e. the dealer is expected to end up with a positive (negative) position in CCP A (B). In that case, the equilibrium expressions for the mid-quotes in each CCP suggest that $m_t^A < \mu_t$ and $m_t^B > \mu_t$ i.e., the mid-quote in CCP A (B) will be lower (higher) than the fundamental value. In other words, mid-quotes across CCPs will be different, giving rise to a *CCP basis*. This is summarized in Proposition 2.

Proposition 2. ***CCP basis***

The ***CCP basis*** *is defined as the difference between the mid-quotes across the two CCPs.*

$$\boldsymbol{Basis}_t \equiv m_t^B - m_t^A = \begin{cases} \frac{2\phi\sigma}{\delta-|(1-\delta)(2\pi-1)|}(z_t^A - z_t^B), & \textit{if} \quad z_{t+1}^A z_{t+1}^B < 0 \\ \frac{\phi\sigma}{\delta} z_t^A, & \textit{if} \quad z_{t+1}^A \neq 0, z_{t+1}^B = 0 \\ \frac{\phi\sigma}{\delta} z_t^B, & \textit{if} \quad z_{t+1}^A = 0, z_{t+1}^B \neq 0 \\ 0, & \textit{if} \quad z_{t+1}^A z_{t+1}^B > 0 \end{cases} \tag{7}$$

Proof. Take the difference between the two mid-quotes in Equation (6).

From expression (7) one can see that the basis is an increasing function of the dealer's inventory imbalance in each CCP $z_t^A - z_t^B$, the riskiness of the asset σ, the unit cost of collateral ϕ and the amount of price-insensitive liquidity traders' directional volume π. On the other hand, it is negatively related to the fraction of price-sensitive liquidity traders δ.

5 Empirical Analysis

5.1 Data

For our empirical analysis we use a variety of data primarily obtained from LCH and CME, covering the period between 1 January 2014 and 30 June 2016. To construct the CME-LCH basis in the USD interest rate swap market, we obtain from both clearing houses the yield curves that they use to price their derivatives contracts. These curves are obtained on a daily frequency for the full sample period and, as we explain in Section 5.2, they reflect dealers' quoted prices for trades cleared with each CCP.

The main body of our data consists of transactions on the full range of products cleared by LCH's SwapClear service, which includes interest rate swaps (IRSs), forward rate agreements (FRAs) and Overnight Index Swaps (OISs), in three main currencies (U.S. Dollar, euro and Pound Sterling). All these contracts belong to the same netting set, meaning that a position in one type of contract can be netted against an offseting position in another contract. LCH has a market share in excess of 90% across all interest rate derivatives in Dollars, Euros and Pound Sterling, and clears approximately 55% of the USD IRS volumes with the rest being cleared by CME.[11] Furthermore, these three currencies represent about 80% of SwapClear volumes.[12] LCH's services are used by almost 100 financial institutions from over 30 countries, including all major dealers. Thus, the LCH data captures the vast majority of activity in interest rate derivatives. The data contains information on contract and trade characteristics such as contract maturity, execution and effective dates, notional amounts traded, execution price (i.e., the contract fixed rate) but also on counterparty identities. This allows us to identify individual dealer activity and also to observe the dealer-to-client segment of the market.[13]

In addition to the transactional data, we also utilize information on the daily amounts of initial margin posted by swap dealers on LCH. Initial margin is collected by LCH to cover losses in the event of a clearing member default and as such, it is calculated daily at the portfolio level using a filtered historical simulation approach.[14]

[11]See Clarus Financial Technology (2017).

[12]See https://www.lch.com/services/swapclear/volumes

[13]We classify as dealers the financial institutions in the the list of 16 "Participating Dealers" used by the OTC Derivatives Supervisors Group, chaired by the New York Fed. For more details see: https://www.newyorkfed.org/markets/otc_derivatives_supervisors_group.html

[14]LCH's model uses 10 years of data to construct the empirical distribution of changes in portfolio values from which the potential loss distribution is calculated. For more details see http://www.swapclear.com/service/risk-management.html.

5.2 The CME-LCH Basis

The CME-LCH basis is the difference in the end-of-day settlement price, of USD-denominated swap contracts with the same maturity, cleared by CME and LCH. Here we reconstruct the CME-LCH basis using the same raw data that the two clearing houses use to calculate end-of-day settlement prices.

At this point it is important to describe how dealers' submitted data translate into a price differential in CCPs' settlement prices. At the end of each day, dealers communicate to the CCPs their quoted swap fixed rates for a number of different maturities. The CCPs then take an average of these quoted prices for each maturity and use them to back out the "zero coupon" yield curve associated with these maturities. The risk-free rates for maturities for which dealers do not report swap price quotes, are interpolated from the extracted yield curve. The interpolated yield curve is then used to derive the settlement prices for any remaining maturities. Thus, any price differential in dealers' quoted prices ultimately shows up in the CCPs' settlement prices. The data we use to re-construct the Basis is the yield curve constructed by CCPs from dealers' submitted quotes. We obtain these yield curves from both LCH and CME for each of the days in our sample period. From these yield curves, we calculate the IRS fixed rates using the standard swap pricing formula, applying the 3M/6M convention, whereby the floating payment is made every 3 months and the fixed payment every 6 months. Let $k \in \{LCH, CME\}$ denote one of the two CCPs. Equating the present values of the fixed and floating payment streams for a T-year contract and for CCP k, we have:

$$\sum_{i=1}^{2T} \frac{R_{k,t}^{fixed,6M,T}/2}{(1+\frac{R_{k,t,i}}{2})^i} = \sum_{j=1}^{4T} \frac{R_{k,t,j}^{floating,3M}/4}{(1+\frac{R_{k,t,j}}{4})^j} \tag{8}$$

where $R_{k,t}^{fixed,6M,T}$ is the day t annualized fixed rate of a T-year maturity contract cleared in CCP k, $R_{k,t,i}$ is the same-day annualized discount rate of period i, extracted by CCP k

(i.e, CCP k's yield curve on day t) and $R_{k,t,j}^{floating,3M}$ is the period j forward rate of CCP k as of day t, extracted from the CCP's yield curve. Thus, the day t CME-LCH basis for a T-year contract is the difference between the two CCP T-year fixed rates as of that day. We calculate these bases for seven different swap maturities, namely for 2, 5, 7, 10, 30, 40 and 50-year contracts and use the simple average of these maturity-specific bases for our empirical analysis:

$$\mathbf{CME-LCH\ \ Basis}_t \equiv \frac{1}{7}\sum_T \left(R_{CME,t}^{fixed,6M,T} - R_{LCH,t}^{fixed,6M,T}\right) \tag{9}$$

In Figure 1 we plot the average CCP basis, over our sample period, on a weekly frequency. As one can see, the average basis fluctuates between 1bps and 3.5bps. Furthermore, it substantially increases from June 2015.[15]

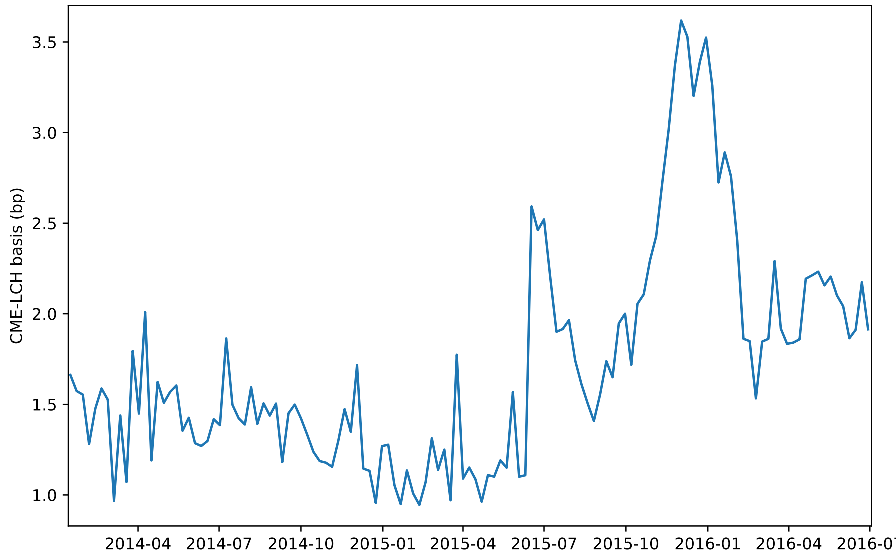
The CME-LCH basis is economically significant. For example, for an indicative average basis of 2bps, LCH client sell (i.e. fixed rate receiving) trades in plain vanilla swaps, across all maturities, would be gaining approximately an additional \$80 million *daily* if they were to execute at CME-prevailing prices.[16] A similar calculation shows that the cost to LCH net selling clients would be around \$3mn daily.

Given that we observe dealer-specific trades on LCH, we also define a proxy for the dealer-specific bases using individual dealers' LCH execution prices. Unfortunately, we do not observe individual dealer activity on CME and so we cannot compare dealers' LCH prices with their CME ones. Instead, we compare dealers' LCH prices with a common benchmark, namely the end-of-day CME settlement price. Thus, our proxy for dealer's d

[15]The increase in the CCP basis could be associated with the phased-in implementation of the Basel III liquidity coverage ratio (LCR), which requires banks to hold high quality liquid asset (HQLA) against their estimated 30 days' cash outflow. IM is counted as cash outflow with a penalization of 20%, i.e., 1 unit of IM counting as 1.2 units of cash outflow. The LCR requirement became effective from Jan 1, 2015 at 60% rate and rose to 70% in 2016. This has likely further increased the cost of IM for dealers. See https://www.bis.org/bcbs/publ/d354.pdf.

[16]The average LCH daily client sell volume, in USD swap contracts, is \$48 billion during our sample period and the volume-weighted average maturity of these contracts is 9.7 years. Thus, a rough estimate of the cost to LCH sellers, associated with the basis, can be calculated as: $2bps \times 10^{-4} \times \$48bn \times \approx \$80mn$.

Figure 1: Average CME-LCH basis (in bps) in USD-denominated IRS contracts as defined in equation (9). The time period is Jan 2014-Jun 2016.



basis for a T-year contract, on day t, is defined as:

$$\mathbf{CME-LCH\ \ Dealer\ \ Basis}_t^d \equiv R_{CME,t}^{fixed,6M} - \bar{R}_{LCH,t}^{fixed,6M,d} \tag{10}$$

where $R_{CME,t}^{fixed,6M}$ is the average (across maturities) fixed rate of USD swap contracts cleared via CME and $\bar{R}_{LCH,t}^{fixed,6M,d}$ is the day t volume-weighted average execution price (across all USD swap contracts), of dealer d on LCH.

5.3 Hypotheses

Our model for the CCP basis gives rise to a number of testable hypotheses. Equation (7) shows that when dealer outstanding inventories in each CCP are expected to be in the opposite direction (i.e., $z_{t+1}^A z_{t+1}^B < 0$), the basis is a function of the per unit cost of collateral ϕ, asset volatility σ, the sum of expected outstanding inventories in the two CCPs $z_t^A - z_t^B$ and the fraction δ of market participants who are price-sensitive and can flexibly choose to clear in either CCP. Asset volatility times the outstanding dealer inventories is an approximation of the amount of collateral posted with each CCP, since, in practice, collateral (or initial margin) is typically calculated as the Value-at-Risk (VaR) of the dealer's portfolio, which is a (multiplicative) function of the portfolio's net notional and risk. Additionally, our model suggests that if clients trade in a direction that minimizes (increases) dealers' imbalances, this will lead to a reduction (increase) in the CCP basis. Thus, with relation to our data, our model gives rise to the following testable hypotheses:

H1: *The CME-LCH basis is increasing in dealers' posted collateral with LCH.*

H2: *The CME-LCH basis is decreasing in the LCH volume share of price-sensitive participants who can clear flexibly in multiple CCPs.*

H3: *The CME-LCH basis is increasing in dealers' credit risk.*

H4: *The CME-LCH basis is decreasing in client net buy volume in USD swap contracts cleared in LCH.*

Regarding the hypotheses that pertain to CCP activity and collateral posted, our model predicts that they should hold true for both LCH and CME. However, we cannot test for any effects on CME-cleared volumes and posted collateral since we only have data from LCH. Therefore, in what follows, we test the above hypotheses using our LCH data.

5.4 Determinants of the CME-LCH Basis

We next use our data to examine the determinants of the CME-LCH basis and also see whether the predictions of our model have empirical validity. We start by testing Hypotheses 1 - 3 using weekly time-series specifications. Our baseline time-series specification is:

$$Basis_t = a + b \cdot Collateral_t + c \cdot Flex\_Ratio_t + d \cdot Libor\_Spread_t + u_t \tag{11}$$

In this setup, *Basis* is the simple average of the end-of-week t value of the CME-LCH basis of each contract maturity as defined in equation (9). *Collateral* is either the aggregate initial margin posted on LCH by all dealers or, the absolute cumulative net volume transacted between dealers and their clients across the full range of SwapClear products, or the 1-month ahead expected Fed Funds rate. This, in turn, is calculated as:

$$Exp\_Fed\_Funds = 100 - Fed\_Funds\_Futures \tag{12}$$

where $Fed\_Funds\_Futures$ is the 1-month Fed Funds futures price. $Flex\_Ratio$ is the fraction of dealer-to-client volume traded across SwapClear products by non-dealer banks and $Libor\_Spread$ is the difference between the three-month Libor rate and the overnight federal funds rate.

The absolute cumulative net volume transacted by dealers is an imperfect proxy for the size of the dealers' aggregate inventory imbalance and is included as a robustness check. This variable is noisy both because we do not observe dealers' initial positions and also because we do not observe contract expirations. The expected Fed Funds rate is used as a proxy for the client buy flow (and associated order imbalance) in swap contracts cleared via CME. The underlying intuition here is that as market participants expect short-term rates to rise, they have an additional incentive to purchase (i.e. to pay fixed in) USD IRS contracts so as to lock in the lower prevailing rate. This client buy flow (assumed here to be primarily US-based) should then exacerbate the CME imbalance that dealers face and should further increase their collateral costs and ultimately the CME-LCH basis.[17] This variable also partially ameliorates the lack of data on dealer collateral and volumes cleared via CME.

We use the fraction of volume traded by non-dealer banks as a proxy for the amount traded by price-sensitive market participants who can clear flexibly in either CCP. We do this because all banks in our sample have access (through their subsidiaries) to both

[17] Given that USD IRS contracts can also be cleared on LCH, the underlying assumption here is that US-based market participants that clear via CME will be more responsive to changing expectations about the Fed Funds rate than non-US participants who would mainly clear via LCH.

LCH and CME and thus can in principle clear through either CCP. This measure may not necessarily capture all market participants with access to both CCPs but it should account for the majority of flexible participants given that most non-bank entities (e.g. asset managers, hedge funds, etc.) typically only access (directly or indirectly) a single CCP.

Both the dealer initial margin, the absolute cumulative net volume and the activity by non-dealer banks pertain exclusively to LCH for which there is available data. In principle, the basis should also be a function of the collateral that the dealers post on CME and of the activity of non-dealer banks that is cleared through this CCP. However, given that dealers try to maintain balanced positions across CCPs, we suspect that any changes in dealer collateral posted in LCH would be highly correlated with changes in collateral posted with CME, to the extent that dealers' CME positions would be approximately offsetting to their LCH positions. Thus, the inclusion of LCH collateral alone in our empirical specification likely captures most of the effect induced by total collateral, posted across both CCPs. For robustness, we also include in our specifications an imperfect proxy of US client buy flow (the expected Fed Funds rate) as discussed above.

Table 1 shows summary statistics for the time-series variables used in the above specification. The aggregate CME-LCH basis fluctuates between 0.9-3.6 bps with an average of 1.7bps. Total collateral posted by dealers on SwapClear is between euro 7-13.8 billions with an average amount of euro 11 billion. Finally, the fraction of volume that all dealers trade with other banks is anywhere between 20%-60% with an average of 34%.

Table 2 shows the estimation results. The predictions of our model are strongly supported in the data with all variables having the expected signs and being statistically significant. Both the amount of initial margin posted by dealers on LCH as well as their absolute cumulative net volume and the expected Fed Funds rate are positively associated

Table 1: Summary statistics of the variables used in specification (11). The aggregate CME-LCH basis (in bps) is the simple average of the maturity-specific bases defined in equation (9). *IM* is the aggregate initial margin posted with the SwapClear service of LCH by all dealers. *AbsCumNetVlm* is the absolute cumulative net dealer-to-client volume in all SwapClear products. *Exp_Fed_Funds* is an estimate of the expected Fed Funds rate and is defined in equation (12). *Flex_Ratio* is the fraction of volume across all SwapClear products that dealers transact with non-dealer banks. *Libor_Spread* is the difference between the three-month USD Libor rate and the overnight federal funds rate. All variables are weekly. The time period is January 2014 to June 2016.

	Mean	*Std*	*Min*	*Max*
Basis (bps)	1.72	.62	.95	3.62
IM (EUR bn)	11.06	1.80	7.11	13.75
AbsCumNetVlm (USD bn)	1834.94	843.39	8.28	3640.46
Exp_Fed_Funds (%)	0.18	0.11	0.07	0.43
Flex_Ratio	.34	.10	.20	.60
Libor_Spread (%)	.07	.02	.04	.17
N	127			

with the CCP basis.[18] The coefficient on the ratio of volume transacted with non-dealer banks is negative and significant consistent with our model's intuition that location-flexible market participants will choose to clear where are prices are keener and in doing so are likely to reduce local dealer imbalances and collateral costs, leading to a reduction in the CCP basis. Finally, the Libor spread is positively associated with the basis consistent with the notion that dealers use the basis to compensate their collateral costs. These costs reflect the debt overhang associated with issuing junior debt in order to fund additional collateral (Andersen et al. (2019)). Consisting of high quality assets (cash, government securities, etc.) collateral reduces the credit risk faced by senior creditors, thus raising the market value of their debt holdings and reducing that of equity holders. The higher the dealers' credit spread (as approximated by the Libor spread), the more pronounced this effect is and the higher the basis needs to be to compensate equity holders. In Section 5.6 we provide further evidence in support of the debt overhang hypothesis. Overall, these results give broad support to the notion that the CCP basis is fundamentally a reflection of dealers' collateral costs and at the same time a means of compensation against these

[18] When both variables enter the specification (column 7), then the cumulative volume variable loses its significance to the initial margin. This is because the initial margin is itself a function of dealer inventory.

costs as predicted by our model.

5.5 Dynamic Effects of the CME-LCH Basis

In our model, dealers set higher (lower) prices where there is persistent client buy (sell) flow. They do this because they want to recoup the collateral costs associated with maintaining imbalanced inventories in each CCP. Thus, as stated in Hypothesis 4 above, our model predicts that the basis will respond over time to client flow in the USD IRS market with the basis increasing (decreasing) whenever clients sell (buy) USD swap contracts on LCH. In this section we test this hypothesis using a Vector Auto-Regression (VARX) model. Our model takes the form:

$$\mathbf{y}_t = a + \sum_{i}^{3}(\mathbf{C}_i\mathbf{y}_{t-i} + d_i X_{t-i}) + u_t, \quad u \sim (\mathbf{0}, \Sigma) \tag{13}$$

where t denotes weeks, $\mathbf{y}_t$ is the vector of endogenous variables and X_{t-1} is a vector of exogenous variables. The endogenous variables are:

$$\mathbf{y}_t = \begin{bmatrix} Flex\_Ratio_t \\ IRS\_Net\_Vlm \\ IM_t \\ Basis_t \end{bmatrix}$$

where IRS_Net_Vlm is the client net (i.e. buy minus sell) volume of USD-denominated IRS contracts, cleared in LCH, and the *Libor_Spread* is treated as exogenous. The rest of the variables are the same as the ones used in our time series regressions. The number of lags in the model is determined by the Schwarz Information Criterion (SIC).

To identify our model we apply short-term restrictions (via a Cholesky decomposition) treating $Flex\_Ratio$ as the most exogenous variable and the basis as the most endogenous one. This ordering is inspired from our model where structural flow imbalances in each

Table 2: Estimation results of the basis time-series model (11). The dependent variable is the CME-LCH basis defined in equation (9). *IM* is the aggregate dealer initial margin posted with LCH, *AbsCumNetVlm* is the absolute cumulative net dealer-to-client volume in all SwapClear products, *Exp_Fed_Funds* is an estimate of the expected Fed Funds rate and is defined in equation (12) and *Flex_Ratio* is the fraction of volume across all SwapClear products that dealers transact with non-dealer banks. *Libor_Spread* is the difference between the three-month USD Libor rate and the overnight federal funds rate. Robust t-statistics are in parentheses. *, ** and *** denote significance at 10%, 5% and 1% respectively. The time period is January 2014 to June 2016.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	basis	basis	basis	basis	basis	basis	basis	basis	basis	basis
IM	0.1412***					0.1319***			0.1772***	0.0468
	(5.44)					(6.11)			(3.87)	(1.42)
AbsCumNetVlm		0.0002***					0.0002***		-0.0001	
		(4.82)					(5.45)		(-1.25)	
Exp_Fed_Funds			3.4803***					2.7899***		2.1877***
			(7.71)					(6.78)		(3.32)
Flex_Ratio				-1.9920***		-1.4049***	-1.3934***	-0.6717*	-1.4764***	-0.7893**
				(-3.97)		(-3.36)	(-3.27)	(-1.90)	(-3.38)	(-2.08)
Libor_Spread					17.1348***	16.7882***	18.7980***	12.6261***	15.7025***	13.4342***
					(6.20)	(7.47)	(7.38)	(5.72)	(6.86)	(5.76)
cons	0.1545	1.3975***	1.1017***	2.3926***	0.5752***	-0.3837	0.5273**	0.6119***	-0.5775	0.1844
	(0.59)	(19.77)	(16.40)	(12.29)	(3.22)	(-1.21)	(2.04)	(3.29)	(-1.65)	(0.53)
R^2	0.170	0.056	0.385	0.094	0.236	0.456	0.398	0.513	0.462	0.521
N	127	127	126	127	127	127	127	126	127	126

CCP increase dealers' IM, which then gives rise to a CCP basis in the USD swap market. However, the results of the VAR model are not sensitive to the particular ordering that we choose.

Figure 2 shows impulse response functions calculated from the estimated coefficients of model (13). Charts (a), (b) and (c) show the impulse responses of the CME-LCH basis to shocks in dealers' posted margin (*IM*), the fraction of client volume traded with non-dealer banks (*Flex_Ratio*) and our estimate of dealers' funding costs (*Libor_Spread*). These responses corroborate the findings of the time-series regressions; they show that both *IM* and *Libor_Spread* have positive and longer-lasting impacts on the CCP basis whereas *Flex_Ratio* has a negative and more short-lived one. Chart (d) shows the response of the basis to a shock in client net volume in USD swaps cleared via LCH and provides a test for Hypothesis 4 described above. The chart shows that when client net volume is positive, the CME-LCH basis decreases. In other words, when clients trade in a direction that reduces dealers' imbalance, the CME-LCH basis shrinks and vice versa. This is consistent with the dynamics of our model where dealers use the basis to recoup their collateral costs.

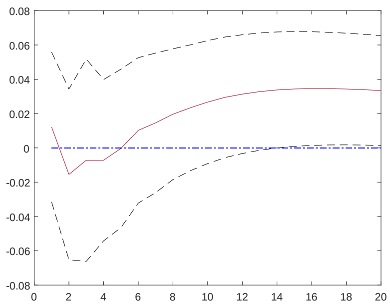
5.6 Dealer Effects

In this section we identify determinants of the CCP basis utilizing dealer-specific information. In particular, we estimate the following fixed (dealer) effects model:

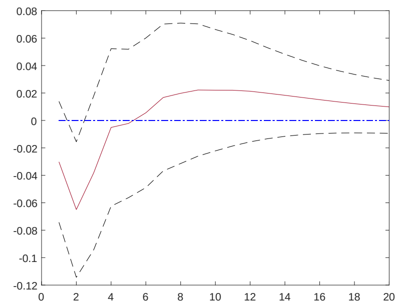
$$DealerBasis_{it} = a + b \cdot Collateral_{it} + c \cdot Flex\_Ratio_{it} + d \cdot CreditRisk_{it} + v_i + u_{it} \quad (14)$$

where i denotes dealers and t denotes weeks. Most of the variables are the same as the ones used in the time-series specification except that they are now calculated at a dealer level. As such, $DealerBasis_{it}$ is the dealer-specific CCP basis as defined in equation (10), $Collateral_{it}$ is either the dealer-specific amount of initial margin posted with LCH or the absolute cumulative net volume traded by the dealer and $Flex\_Ratio_{it}$ is the dealer-specific

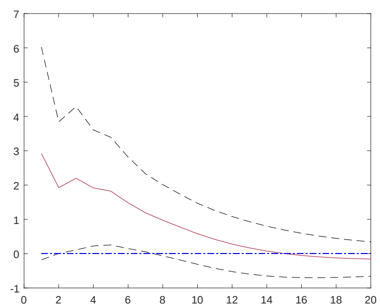
Figure 2: Impulse response functions obtained from estimating model (13). The CME-LCH basis defined in equation (9). *IM* is the total initial margin posted by swap dealers on LCH, *Flex_Ratio* is the fraction of volume across all SwapClear products that dealers transact with non-dealer banks, *Libor_Spread* is the difference between the three-month USD Libor rate and the overnight federal funds rate and *IRS_Net_Vlm* is the client net (i.e. buy minus sell) volume in USD interest rate swap contracts cleared in LCH. The dotted lines show the 95% confidence intervals of the estimated impulse responses.



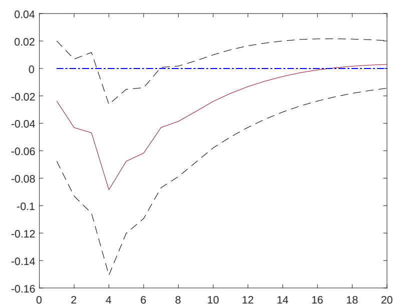
(a) Impact of *IM* on *Basis*



(b) Impact of *Flex_Ratio* on *Basis*



(c) Impact of *Libor_Spread* on *Basis*



(d) Impact of *IRS_Net_Vlm* on *Basis*

fraction of traded volume with non-dealer banks. To test the debt overhang hypothesis, we also include in the specification variables intended to capture individual dealers' credit risk. As such, $CreditRirsk_{it}$ is either each dealer's CDS spread (or that of their parent company) or their equity ratio, defined as market value of equity over book value of assets. The model is estimated using dealer-specific fixed effects to account for unobservable, time-invariant, heterogeneity across dealers.

Summary statistics for the panel variables used in the above specification are shown in Table 3. The average dealer-specific basis is around 1bps but fluctuates substantially and for some dealer-weeks also turns negative.[19] On average, each dealer posts around 0.46bn euros of collateral with SwapClear-LCH at any given week, but there is substantial variation across dealers-weeks with a minimum of around euro 10,000 and a maximum of euro 2.5bn. Similarly, the other activity variables also exhibit higher variability than their aggregated time-series counterparts reflecting differences across dealers.

The results of various regressions nested in specification (14) are shown in Table 4. All the main hypotheses continue to be supported in the data with IM, $AbsCumNetVlm$ and $Flex\_Ratio$ having the expected signs. Furthermore, our results are consistent with the Andersen et al. (2019) debt overhang hypothesis as dealer CDS spreads (equity ratios) are positively (negatively) associated with our proxy for the dealer-specific basis. In other words, as dealers' credit risk increases and debt overhang becomes more pronounced, dealer-banks' equity holders require a higher compensation, in the form of a basis, for the wealth transfer accruing to senior creditors when additional collateral is posted to the clearing house.

Table 3: Summary statistics, over dealer-weeks, of the variables used in specification (14). $DealerBasis_{it}$ is the dealer-specific CCP basis as defined in equation (10). *IM* is the initial margin posted with the SwapClear service of LCH by each dealer. *AbsCumNetVlm* is the dealer-specific absolute cumulative net volume in all SwapClear products. *Flex_Ratio* is the fraction of total client volume, across all SwapClear products, that each dealer transacts with non-dealer banks. *CDS* is the dealer CDS spread and *Equity* is dealer ratio of market value of equity over book value of assets. The time period is January 2014 to June 2016.

	Mean	*Std*	*Min*	*Max*	*N*	*Frequency*
DealerBasis (bps)	.99	1.37	-3.89	7.11	2722	Weekly
IM (EUR bn)	.46	.32	.0001	2.50	2778	Weekly
AbsCumNetVlm (USD bn)	109.9	155.4	0.1	830	3119	Weekly
RatioFlex	.47	.27	0	1	3120	Weekly
CDS spreads (bps)	77.54	22.01	34.90	234.7	1810	Weekly
Equity	0.06	0.04	0.01	0.17	1806	Quarterly

[19] However, one needs to bear in mind that our dealer-specific basis is a noisy proxy of the actual variable which is not observable to us.

Table 4: Estimation results of the dealer basis panel model (14). The dependent variable is the proxy for the dealer-specific CME-LCH basis defined in equation (10). *IM* is the individual dealer initial margin posted with LCH, *AbsCumNetVlm* is the dealer absolute cumulative net client volume in all SwapClear products and *Flex_Ratio* is the fraction of volume across all SwapClear products that each dealer transacts with non-dealer banks. *CDS* is the CDS spread and *Equity* is the market value of equity over the book value of assets of either the individual dealer itself or of the dealer's parent company. Robust t-statistics are in parentheses. *, ** and *** denote significance at 10%, 5% and 1% respectively. The time period is January 2014 to June 2016.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	basis	**basis**	**basis**	**basis**	**basis**	**basis**	**basis**	**basis**	**basis**	**basis**
IM	1.5228***					1.4425***	1.4282***	1.1179***		1.0780**
	(4.13)					(3.65)	(3.89)	(3.29)		(2.97)
AbsCumNetVlm		0.0032***							0.0026**	0.0023**
		(5.04)							(2.47)	(2.29)
Flex_Ratio			-0.7061***			-0.3930	-0.5399*	-0.5423**	-0.5257*	-0.5733**
			(-2.96)			(-1.69)	(-1.98)	(-2.52)	(-2.11)	(-2.90)
CDS				0.0175***		0.0148***		0.0156***	0.0136***	0.0124***
				(4.16)		(3.86)		(3.89)	(3.53)	(3.44)
Equity					-36.0861***		-26.9507***	-12.5804	-18.9771*	-13.3534
					(-4.25)		(-3.06)	(-1.21)	(-1.84)	(-1.33)
cons	0.2842	0.6243***	1.3220***	-0.4285	3.2075***	-0.7103**	2.2214***	0.3011	1.1737	0.4497
	(1.62)	(8.48)	(11.96)	(-1.31)	(6.05)	(-2.61)	(3.41)	(0.29)	(1.35)	(0.49)
R^2	0.045	0.052	0.008	0.062	0.056	0.104	0.104	0.130	0.124	0.144
N	2585	2722	2722	1736	1733	1655	1652	1468	1549	1468

6 Conclusion

With central clearing becoming a key feature of OTC derivatives markets after the financial crisis, questions regarding the scope and size of CCPs are becoming increasingly important. Our paper sheds light on such a question, namely what happens when clearing in comparable products is fragmented across multiple CCPs. In this context, we document an economically significant price differential between the same USD-denominated swap contracts cleared in CME and LCH (the CME-LCH basis) and argue that this is a result of dealers seeking compensation for bearing increased collateral costs when clearing is fragmented. To formalize our argument, we employ a dealer inventory cost management framework and, using CCP data on prices, transactions and collateral, we provide empirical evidence consistent with this explanation.

More generally, our paper highlights the emerging importance of the post-trade cycle (which includes clearing and settlement) for asset pricing. Technological and regulatory developments in this area have changed (and are likely to continue to change) the institutional arrangements under which securities and financial contracts have traditionally been traded. Understanding then the impact of these changes on financial asset prices, is a fruitful area of further research and one with potentially important policy implications.

Appendix

Lemma 1. ***Expected order flow from liquidity traders in the two CCPs***

The expected order flow by liquidity traders, in each CCP, depends on the relationship between mid-quotes (m_t^i) and the intrinsic value (μ_t) and is given by the expressions in the following table:

	CCP A: $E_t[d_t^A]$	*CCP B:* $E_t[d_t^B]$
$\mu_t \leq m_t^A < m_t^B$	$\frac{1}{2}(1-\delta)(2\pi-1)$	$\frac{1}{2}(1-\delta)(1-2\pi)-\delta$
$m_t^A < \mu_t < m_t^B$	$\frac{1}{2}(1-\delta)(2\pi-1)+\frac{1}{2}\delta$	$\frac{1}{2}(1-\delta)(1-2\pi)-\frac{1}{2}\delta$
$m_t^A < m_t^B \leq \mu_t$	$\frac{1}{2}(1-\delta)(2\pi-1)+\delta$	$\frac{1}{2}(1-\delta)(1-2\pi)$
$\mu_t < m_t^A = m_t^B$	$\frac{1}{2}(1-\delta)(2\pi-1)-\frac{1}{2}\delta$	$\frac{1}{2}(1-\delta)(1-2\pi)-\frac{1}{2}\delta$
$m_t^A = m_t^B = \mu_t$	$\frac{1}{2}(1-\delta)(2\pi-1)$	$\frac{1}{2}(1-\delta)(1-2\pi)$
$m_t^A = m_t^B < \mu_t$	$\frac{1}{2}(1-\delta)(2\pi-1)+\frac{1}{2}\delta$	$\frac{1}{2}(1-\delta)(1-2\pi)+\frac{1}{2}\delta$
$\mu_t \leq m_t^B < m_t^A$	$\frac{1}{2}(1-\delta)(2\pi-1)-\delta$	$\frac{1}{2}(1-\delta)(1-2\pi)$
$m_t^B < \mu_t < m_t^A$	$\frac{1}{2}(1-\delta)(2\pi-1)-\frac{1}{2}\delta$	$\frac{1}{2}(1-\delta)(1-2\pi)+\frac{1}{2}\delta$
$m_t^B < m_t^A \leq \mu_t$	$\frac{1}{2}(1-\delta)(2\pi-1)$	$\frac{1}{2}(1-\delta)(1-2\pi)+\delta$

Proof of Lemma 1:

Total liquidity trader flow is the sum of the flows of the price-insensitive and price-sensitive traders. Price-insensitive flow imbalance in CCP A is $\frac{1}{2}(1-\delta)(2\pi-1)$ and in CCP B is $\frac{1}{2}(1-\delta)(1-2\pi)$. Price-sensitive order flow depends on the relationship between the mid-quotes and the intrinsic value. There are three cases: (i) $m_t^A < m_t^B$, (ii) $m_t^A = m_t^B$, and (iii) $m_t^A > m_t^B$. When $m_t^A < m_t^B$, μ_t could be smaller than m_t^A, larger than m_t^A but less than m_t^B, or larger than m_t^B. In the first case, price sensitive traders will only sell in CCP B. Hence, their flow is zero in CCP A and $-\delta$ in CCP B. In the second case, price sensitive traders in CCP A will buy and those in CCP B will sell. Hence, their flow will equal $\frac{1}{2}\delta$ in CCP A and $-\frac{1}{2}\delta$ in CCP B. In the last case, price sensitive traders will only buy in CCP A, Hence, their flow will be δ in CCP A and zero in CCP B.

When $m_t^A = m_t^B$, price sensitive traders will use their local CCPs. If μ_t is smaller than the mid-quotes, they will sell. Hence, their flow will be $-\frac{1}{2}\delta$ in both CCPs. If μ_t is equal to the mid-quotes, they will not trade and the flows will be zero in both CCPs. Finally, if μ_t is bigger than the mid-quotes, price sensitive traders will buy. Hence, their flows will be $\frac{1}{2}\delta$ in both CCPs. Exactly symmetric arguments apply when $m_t^A > m_t^B$.

Proof of Proposition 1:

To derive the rational expectations equilibrium, we conjecture a linear relationship between quoted prices and dealer inventories. In particular, we conjecture that quoted prices should reflect a mark-down (or mark-up) on the fundamental asset price, because of dealer collateral costs. As such, quoted prices in each CCP are functions of inventories in both CCPs:

$$\begin{bmatrix} p_t^A \\ p_t^B \end{bmatrix} = \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \begin{bmatrix} \beta_1 & \beta_2 \\ \beta_3 & \beta_4 \end{bmatrix} \begin{bmatrix} z_{t+1}^A \\ z_{t+1}^B \end{bmatrix}$$

In matrix form, this can be written as:

$$\boldsymbol{p_t} = \boldsymbol{\mu_t} - \boldsymbol{\beta} \boldsymbol{z_{t+1}} = \boldsymbol{\mu_t} - \boldsymbol{\beta}(\boldsymbol{z_t} - \boldsymbol{q_t}) \tag{A1}$$

Taking expectations, this gives us:

$$\begin{aligned} \boldsymbol{E_t}[\boldsymbol{p_{t+1}}] =& \boldsymbol{E_t}[\boldsymbol{\mu_{t+1}}] - \beta \boldsymbol{E_t}[\boldsymbol{z_{t+1}}] + \beta \boldsymbol{E_t}[\boldsymbol{q_{t+1}}] \\ =& \boldsymbol{\mu_t} - \boldsymbol{\beta} \boldsymbol{z_{t+1}} + \boldsymbol{\beta} \boldsymbol{E_t}[\boldsymbol{q_{t+1}}] \\ =& \boldsymbol{p_t} + \boldsymbol{\beta} \boldsymbol{E_t}[\boldsymbol{q_{t+1}}] \end{aligned} \tag{A2}$$

Now let $\Delta \equiv \frac{1}{2}(1-\delta)(2\pi-1)$. From Lemma 1, we have the following order flow patterns for each inventory configuration:

		$E_t[d_t^A]$	$E_t[d_t^B]$	z_{t+1}^A	z_{t+1}^B
1.	$\mu_t \leq m_t^A < m_t^B$	Δ	$-\Delta - \delta$	≤ 0	< 0
2.	$m_t^A < \mu_t < m_t^B$	$\Delta + \frac{1}{2}\delta$	$-\Delta - \frac{1}{2}\delta$	> 0	< 0
3.	$m_t^A < m_t^B \leq \mu_t$	$\Delta + \delta$	$-\Delta$	> 0	≥ 0
4.	$\mu_t < m_t^A = m_t^B$	$\Delta - \frac{1}{2}\delta$	$-\Delta - \frac{1}{2}\delta$	< 0	< 0
5.	$m_t^A = m_t^B = \mu_t$	Δ	$-\Delta$	$= 0$	$= 0$
6.	$m_t^A = m_t^B < \mu_t$	$\Delta + \frac{1}{2}\delta$	$-\Delta + \frac{1}{2}\delta$	> 0	> 0
7.	$\mu_t \leq m_t^B < m_t^A$	$\Delta - \delta$	$-\Delta$	< 0	≤ 0
8.	$m_t^B < \mu_t < m_t^A$	$\Delta - \frac{1}{2}\delta$	$-\Delta + \frac{1}{2}\delta$	< 0	> 0
9.	$m_t^B < m_t^A \leq \mu_t$	Δ	$-\Delta + \delta$	≥ 0	> 0

There are now several different cases:

(I) when $z_{t+1}^A z_{t+1}^B > 0$, the first order conditions of the dealer's problem in equations (3) and (4) imply:

$$\begin{bmatrix} E_t[p_{t+1}^A] - p_t^A \\ E_t[p_{t+1}^B] - p_t^B \end{bmatrix} = \begin{cases} \begin{bmatrix} -\phi\sigma \\ -\phi\sigma \end{bmatrix}, & \text{if } z_{t+1}^A < 0, z_{t+1}^B < 0 \\ \begin{bmatrix} \phi\sigma \\ \phi\sigma \end{bmatrix}, & \text{if } z_{t+1}^A > 0, z_{t+1}^B > 0 \end{cases} \tag{A3}$$

This case corresponds to rows 4 and 6 in the above table. So, from the order flow values in these rows, from equations (A2) and (A3) and the market clearing condition $d_t^i = q_t^i$, we have that:

$$\boldsymbol{\beta} = \frac{\phi\sigma}{\delta} \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$

(II) Similarly, when $z_{t+1}^A z_{t+1}^B < 0$ equations (3) and (4) imply:

$$
\begin{bmatrix} E_t[p^A_{t+1}] - p^A_t \\ E_t[p^B_{t+1}] - p^B_t \end{bmatrix} = \begin{cases} \begin{bmatrix} -\phi\sigma \\ \phi\sigma \end{bmatrix}, & \text{if } z^A_{t+1} < 0, z^B_{t+1} > 0 \\ \begin{bmatrix} \phi\sigma \\ -\phi\sigma \end{bmatrix}, & \text{if } z^A_{t+1} > 0, z^B_{t+1} < 0 \end{cases} \tag{A4}
$$

Again, using the values of the client order flows for this case (rows 2 and 8 in the above table) along with equations (A3) and (A2) and the market clearing condition, we obtain:

$$
\boldsymbol{\beta} = -\frac{\phi\sigma}{\delta - |2\Delta|} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}
$$

(III) Finally, when $z^A_{t+1} z^B_{t+1} = 0$ equations (3) and (4) imply:

$$
\begin{bmatrix} E_t[p^A_{t+1}] - p^A_t \\ E_t[p^B_{t+1}] - p^B_t \end{bmatrix} = \begin{cases} \begin{bmatrix} -\phi\sigma \\ 0 \end{bmatrix}, & \text{if } z^A_{t+1} < 0, z^B_{t+1} = 0 \\ \begin{bmatrix} 0 \\ -\phi\sigma \end{bmatrix}, & \text{if } z^A_{t+1} = 0, z^B_{t+1} < 0 \\ \begin{bmatrix} \phi\sigma \\ 0 \end{bmatrix}, & \text{if } z^A_{t+1} > 0, z^B_{t+1} = 0 \\ \begin{bmatrix} 0 \\ \phi\sigma \end{bmatrix}, & \text{if } z^A_{t+1} = 0, z^B_{t+1} > 0 \\ \begin{bmatrix} 0 \\ 0 \end{bmatrix}, & \text{if } z^A_{t+1} = 0, z^B_{t+1} = 0 \end{cases} \tag{A5}
$$

Doing similar calculations as in the other cases, we have:

$$\boldsymbol{\beta} = -\frac{\phi\sigma}{\delta}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Inserting the values of the estimated parameter vectors $\boldsymbol{\beta}$ in equation (A1) yields the expressions in (5) for quoted prices. The expressions for the mid-quotes are easily obtained by taking the average of the quoted bid and ask prices. These, in turn, are derived by setting $q_t = -1, +1$ respectively in equation (A1). Thus, for CCP i, the quoted bid and ask prices are:

$$\text{Bid: } p_t^i = \mu_t - \beta z_t - \beta$$

$$\text{Ask: } p_t^i = \mu_t - \beta z_t + \beta$$

Taking the average of these two gives the mid-quote:

$$m_t = \mu_t - \beta z_t$$

Inserting the values of $\boldsymbol{\beta}$ in this expression, yields equation (6).

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