The Cost of Clearing Fragmentation

Abstract

Fragmenting clearing across multiple central counterparties (CCPs) is costly because global dealers cannot net positions across CCPs. They have to collateralize both the short position in one CCP *and* an offsetting long position in another CCP. This observation coupled with a structural net order imbalance across CCPs can cause prices to persistently differ across them ("the CCP basis"). We propose a model to rationalize this basis and derive several hypotheses. Testing these on unique CCP data for interest-rate derivatives, yields broad empirical support for the model and suggests that the clearing friction costs sellers clearing in LCH \$80 million *daily*.

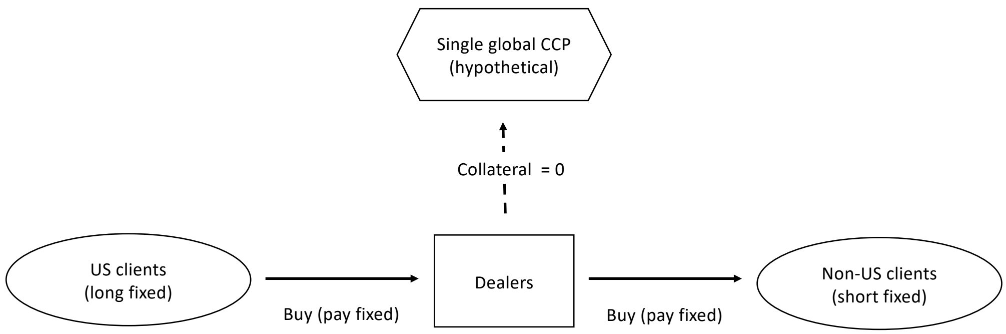
1 Introduction

To address counterparty risk, the G20 mandated central clearing of standardized derivatives after the 2007-2008 financial crisis. Any trade in, for example, a USD fixed-to-floating interest-rate swap needs a central counterparty (CCP) to insure counterparty risk. Should one side of the trade fail on its commitments, the CCP steps in and effectively becomes the new counterparty to honor the outstanding commitments. To protect itself, the CCP requires participants to post collateral (i.e., initial margin) commensurate to the size of their commitments.[1]

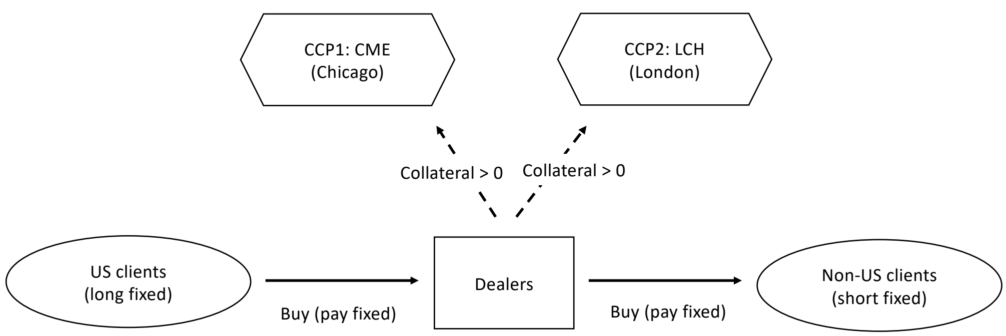
International securities markets (including derivatives) allow local economic exposures to be shared globally thus efficiently transferring risk. End-user investors therefore trade across jurisdictions. Some investors, however, might be constrained, either by regulation or by cost, to trade within their own jurisdiction. Global dealers step in to trade with these investors locally while aiming to keep their global net position zero. Even if the hedge is perfect (i.e., dealers keep their global net position zero), fragmented clearing implies that the dealers have to post collateral with the local CCPs for non-zero local positions. Dealers recoup these costs by trading with their clients at different price levels in the various local markets. The market with predominantly sellers gets a lower price than the market with predominantly buyers. This price differential is referred to as the "CCP basis."

Figure 1 illustrates the cost of fragmented clearing for the case of USD interest-rate swaps. US local banks selling fixed-rate mortgages, for example, hedge these exposures by "buying" (i.e., paying fixed) from global dealers. These dealers, in turn, hedge these positions by trading with international investors in London. If, as in panel (a), there were a single global CCP, the dealers would be able to net these positions and therefore would not have to post initial margin. Panel (b) shows that, in reality, the trade between the US banks and the dealers will be cleared in the Chicago Mercantile Exchange (CME), while that between the dealers and the international investors will be cleared in LCH in London. The dealers have to post margin at both CME and LCH. This is costly to dealers not only because margin needs to be funded by tapping capital markets but also

[1] The interest-rate derivatives market is the largest derivatives market by far in terms of outstanding notional. At the end of 2019, the notional stood at $344 trillion with 77% of it being centrally cleared.



(a) Single CCP



(b) Multiple CCPs

Figure 1: Single vs. multiple CCPs

This figure illustrates how imbalanced order flow across two pools of investors served by different CCPs can impose non-zero collateral costs on dealers. The figure depicts the case of US clients who hedge their long positions in USD fixed rates (due to, e.g., banks selling fixed-rate mortgages) with, ultimately, non-US clients. Panel (a) illustrates the hypothetical case of a single global CCP. Panel (b) illustrates the real-world case of global dealers clearing with US clients at CME in Chicago and with non-US clients at LCH in London.

because of debt overhang (Andersen et al., 2019).[2]

Dealers recoup the cost of not being able to net positions across CCPs by charging their clients. They do so by charging the net buyers in the US a higher price than the net sellers outside of the US.[3] This price differential, the so-called "CCP basis," is one to four basis points in our 2014-2016 sample for USD interest rate swaps. The basis may seem small but multiplied by daily volume this costs LCH sellers about $80 million, *per day*.[4]

Clearing fragmentation is not unique to USD interest-rate swaps. Other examples include (i) EUR interest-rate swaps being cleared by LCH and by Eurex in Frankfurt, and (ii) JPY swaps being cleared by LCH and by the Japan Securities Clearing Corporation (JSCC). Additionally, there is scope for clearing to further fragment in the near future as a result of "location policies" that effectively require systemically important CCPs to migrate part of their business to the home jurisdiction of some of its clearing members.[5]

Our goal is to analyze the economics of fragmented clearing. For this, we adapt a canonical inventory model (Foucault et al., 2013) to characterize the behavior of dealers that clear in two separate locations. Our model gives rise to several hypotheses which we test in a 2014-2016 sample of proprietary collateral and transactions data on interest-rate derivatives.

Before turning to the results in more detail, let us position our study in the current literature.[6] Duffie and Zhu (2011) made the point that from a collateral-saving perspective, it is best

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[2] To the extent that margin 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.

[3] The basis (CME minus LCH) being positive could be explained, as stated earlier, by hedging needs of US banks selling fixed-rate mortgages. Such hedging is particularly important in a cycle of rate hikes. In summer 2019, however, the Fed started a rate-cut cycle. The basis turned negative at this time. This could be explained by US banks discontinuing the hedge (to benefit from the expected rate cuts), coupled with a desire of US investors to enter short positions (i.e., receiving fixed and paying floating rates). Our model shows how such switch from positive to negative net imbalance in the US is consistent with the basis flipping sign.

[4] 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=.

[5] For example, in its latest update, the European Markets Infrastructure Regulation (EMIR) prohibits clearing members domiciled in the European Union (EU) from accessing the services of third-country CCPs deemed by regulators to be systemically important. Commentators have argued that this rule is likely to apply to LCH following the departure of the United Kingdom from the EU. For additional information on the treatment of CCPs under EMIR see here: https://www.esma.europa.eu/policy-rules/post-trading/central-counterparties.

[6] Menkveld and Vuillemey (2020) survey the burgeoning literature on central clearing.

to organize all clearing in a single CCP.[7] Garleanu and Pedersen (2011) show how collateral cost enters equilibrium asset prices. We essentially combine these two insights to show how fragmented clearing can cause prices to deviate from the "law of one price." To the best of our knowledge, we are the first to offer an explanation for the puzzling finding of a non-zero CCP basis.

The model formally establishes a link between the CCP basis and dealer collateral cost. The intuition is similar to what classic inventory models predict for how inventories relate to prices. If risk-averse dealers are long relative to their target positions, they optimally skew their prices downwards so that they slide below fundamental value, causing price pressures (Amihud and Mendelson, 1980; Ho and Stoll, 1981; Hendershott and Menkveld, 2014). These price pressures help reduce inventory given that low asks make it cheap to buy from the dealer and low bids make it unattractive to sell to the dealer.

The classic inventory friction however does not deliver a basis across markets. It can explain why prices in both markets slide above or below fundamental value, it cannot explain why prices *differ* across markets. If one adds the friction that a non-zero inventory carries collateral cost, as CCPs require initial margin that scales with inventory, then one *can* generate a non-zero basis. More precisely, if clearing is fragmented across markets, then each CCP requires collateral proportional to the inventory the dealer holds in his market only, and a non-zero CCP basis can arise.

A simple example will clarify the insights that our inventory model delivers. Consider a dealer trading a single security in two markets: X and Y. Each market has their trades cleared by a local CCP. Each CCP requires the dealer to post margin that scales with the dealer's inventory *in the local market only.* Now consider the case where the dealer is long one unit in X, and long one unit in Y. Our model shows that there is no basis in equilibrium. The equilibrium price in both markets exhibits negative price pressure, which means that it is below the fundamental value. Since the size of this price pressure is equal across markets, there is no price differential across markets, and the basis therefore is zero. If, however, the dealer is *short* one unit in Y, then equilibrium prices imply a non-zero basis. The dealer desires to sell in X, resulting in a negative price pressure in X.

[7] Garratt and Zimmerman (2020) extend this work in more realistic networks of exposures. The extent of netting opportunities to save on collateral has also been an important criterion for policy makers when assessing various clearing arrangements (Singh, 2009, 2013; Sidanius and Zikes, 2012).

In Y, however, he desires to buy resulting in a positive price pressure in Y.

The model delivers several equilibrium relationships between this price differential—the basis—and various other variables. We use these to state the following hypotheses:

1. The basis grows in the amount of collateral pledged by dealers.

2. The basis declines in the proportion of investors who can access markets outside of their jurisdiction.

3. The basis grows in dealer credit risk, because collateral becomes costlier to them.

4. The relationships hypothesized thus far are stronger for longer-maturity contracts as these are riskier and therefore require more collateral.

5. Dynamically, if in response to the CCP basis, the high-price market attracts more investor sell flow and the low-price market more investor buy flow, then the basis will shrink subsequently.

We test these hypotheses using proprietary data from LCH's SwapClear service, from January 2014 to June 2016. The data include the amounts of own collateral pledged by the participating dealers as well as 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). An important feature of our data is that it identifies counterparties. This allows us (i) to isolate dealer and client activity and (ii) to identify non-dealer banks who can flexibly clear their trades in the CCP of their choosing.

We find broad support in the data for the hypotheses implied by our model. Both the collateral pledged by dealers and their credit spread correlate positively with the size of the CME-LCH basis. The proportion of volume in SwapClear products executed by non-dealer banks, a proxy for investors who can clear flexibly, correlates negatively with the size of the basis. These effects are stronger for longer maturity contracts. Finally, impulse response functions based on VARX model estimates lend empirical support for the final hypothesis on model dynamics. A *positive* net volume shock for trades that are cleared at LCH where contracts trade at lower prices, is followed by a decline in the CCP basis (i.e., it becomes smaller in magnitude).

Position in the broader literature. Our findings on how fragmented clearing can lead to economically meaningful price distortions add to the larger literature on intermediary-based asset pricing. It is well documented that dealer inventory cost affects prices for 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, 2019).

More recent studies focus on how regulation affects dealer balance sheets and, in turn, their ability to make markets. Andersen et al. (2019) articulate how, in the presence of debt overhang, the posting of collateral results in funding value adjustments that dealers ultimately pass on to their clients. 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) and Cenedese et al. (2020a) show that constraints on bank balance 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. (2020b) 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 clients via the so-called valuation adjustments (XVA). Ranaldo et al. (2019) show that prices for European repos drop during quarterly reporting periods when Basel III leverage ratio requirements constrain bank repo borrowing demand the most.

Similarly, recent evidence suggests that dealer balance sheet constraints can affect their trading activity. For instance, Kotidis and van Horen (2018) document reduced Sterling repo dealer volumes and Benos and Zikes (2018) document reduced gilt inter-dealer volumes as a result of tightened dealer balance sheets. Additionally, Acosta-Smith et al. (2018) find that such 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 adds that clearing arrangements are a key part of the collateral costs for dealers and are passed on to end-user investors via a basis.

Our analysis of the CCP basis further contributes to a larger literature that studies a non-zero basis in other contexts. For example, studies on the index-futures basis, the price differential between a market index and an accompanying index futures, include Miller et al. (1994), Kumar and Seppi (1994), and Dwyer et al. (1996). More recent literature focuses on the CDS-bond basis which captures the price gap between a risk-free bond and a synthetic risk-free bond: A corporate bond plus a credit default swap (CDS) (e.g. Bai and Collin-Dufresne, 2019). Our CCP basis differs from these types of basis in the sense that it is not driven by a classic "limit-to-arbitrage" friction, but a financial-architecture friction.

In sum, the analysis contributes to the literature by showing that clearing fragmentation is costly to dealers, a cost that is passed on to their clients. The model reveals the economic mechanism and the empirical analysis shows that the model predictions are consistent with the data. It suggests that the costs are non-trivial for hedging USD interest rates. We would like to emphasize that the data itself are part of our contribution to the literature. We are the first to have access to initial-margin data on interest-rate derivatives, an asset class where arguably most risk is exchanged globally.

We believe that our message on clearing fragmentation transcends the derivatives we studied. Given that it must be true that many economic exposures of local investors are best hedged by trading with foreign investors who reside outside of their jurisdictions, we believe this fragmented-clearing friction is of first-order importance. We acknowledge that there are benefits to local CCPs (e.g., more regulatory oversight) but our analysis points out that the economic costs are non-trivial.

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

2 Institutional Framework

2.1 Central clearing and initial margin

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 initial margin, daily, or sometimes even intra-day, to cover potential losses in the event of a clearing member default.[8] 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 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, positions in different services within the same CCP (i.e. positions that are not in the same netting set) or positions in the same contracts cleared 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., central clearing of certain standardized IRS contracts has been mandatory for U.S. persons since March 2013. The EMIR clearing obligation was phased-in from June 2016 and required European counterparties of certain OTC interest rate derivatives to clear their transactions through an authorized CCP. As a result of the clearing obligation, the

[8] 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: https://www.lch.com/system/files/media_root/2a%20Default%20Waterfall%20Ltd%200.35%20200430%20SIG.pdf.

centrally-cleared segment of interest rate derivatives dominates trading during our sample period.[9]

2.2 Clearing fragmentation in the IRS market

Clearing in the USD-denominated segment of the IRS market is dominated by two clearing houses, LCH and 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. 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. It offers products in 19 currencies and has about 80 clearing members.

LCH has a market share in excess of 90% across all interest rate derivatives in USD, EUR and GBP, and clears approximately 55% of the USD IRS volumes with the rest being cleared by CME.[10] Furthermore, these three currencies represent about 80% of SwapClear volumes.[11] Thus, our LCH data captures the vast majority of activity in interest rate derivatives.

3 A model for the CCP basis

Our model is based on the inventory-holding cost model in Foucault et al. (2013, Sec. 3.5). Consider a representative risk-neutral dealer who is perfectly competitive. He makes markets for a single type of derivative contract (e.g., a plain vanilla fixed-to-floating IRS). There are infinitely many time periods. In each period t, there is a unit mass of liquidity traders who like to buy or sell the contract. They can only do so by trading with the dealer and have to clear their trades in either CCP X or CCP Y. Crucially, the dealer cannot net his position across these two CCPs and therefore is required to post initial margin with a CCP based on his position with this CCP only. Information is symmetric across all agents in the model. The model details are as follows.

[9] For example, Cenedese et al. (2020b) report that in 2015 90% of USD swap volumes and 85% of trades are centrally cleared.

[10] See Clarus Financial Technology (2017).

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

The contract. 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:

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

Let p_t^k denote the price of the contract that clears in CCP k at time t, which is not necessarily equal to the fundamental value μ_t. For the rest of the section, we use "price in CCP k" when referring to "price of the contract that clears in CCP k." Similarly, we use "buy in CCP k" when referring to "buy the contract that clears in CCP k."

The liquidity traders. There is a unit mass of liquidity traders who either buy or sell one unit, but not both. The traders are equally split between the two CCPs.

A proportion δ of liquidity traders is price-sensitive and also has access to the other CCP. Their private value of the contract is equal to the fundamental value (i.e., there is no intrinsic buy or sell interest). If there is a CCP with a price that strictly deviates from fundamental value, then they trade. They trade in the CCP with the best deal and, in case both CCPs are tied in terms of the best deal, then they pick their local CCP. For example, consider the case where fundamental value is zero. If a price-sensitive trader in X is quoted a price of minus one in X and plus two in Y, then he will sell one unit in Y. If, instead, the price in Y were plus one, then he would buy in X. One way to think of these traders is as "arbitrageurs."

The remaining proportion of liquidity traders, $1 - \delta$, only has access to their local CCP. They are in the market to either buy or sell one unit. They are price-insensitive. In CCP X, a proportion π of them buys and $1 - \pi$ sells. The opposite is the case in CCP Y. The price-insensitive net order flow therefore is balanced *across* CCPs, but not necessarily within a CCP (i.e., this is true only when $\pi = \frac{1}{2}$). In sum, the net price-insensitive flow in CCP X is: $\frac{1}{2}(1 - \delta)(2\pi - 1)$. In CCP Y, it is $\frac{1}{2}(1 - \delta)(1 - 2\pi)$.

Lemma 1 in the Appendix summarizes the aggregate net liquidity demand for all possible price pairs. This aggregate flow includes the flow of both price-sensitive and price-insensitive liquidity traders.[12]

The dealer. All liquidity traders trade with a risk-neutral, representative, and perfectly competitive dealer. The dealer takes the price as given and chooses the quantity that he is willing to supply. For simplicity, we assume a zero-spread in both CCPs as the focus is about the price differential across CCPs. The dealer clears in both CCPs but, crucially, he cannot net any offsetting positions across CCPs. At the end of period t, the dealer's position in CCP k is z_{t+1}^k. The dealer's aggregate position across CCPs is $z_{t+1} = z_{t+1}^X + z_{t+1}^Y$.[13] The net quantity that he supplies to liquidity traders, q_t^k, affects his position change in period t as follows: $z_{t+1}^k = z_t^k - q_t^k$ (i.e., traders buy from him if $q_t^k > 0$ and sell to him if $q_t^k < 0$). For this end-of-period position with CCP k, he needs to post collateral as initial margin. The amount of collateral typically equals the value-at-risk (VaR) associated with the position, which we model as $\sigma|z_{t+1}^k|$.[14]

The dealer funds each unit of collateral at a cost φ. One interpretation of such cost is the debt overhang cost accruing to shareholders as proposed by Andersen et al. (2019). Given that the dealer cannot net his positions across CCPs, the total collateral cost of the dealer is:

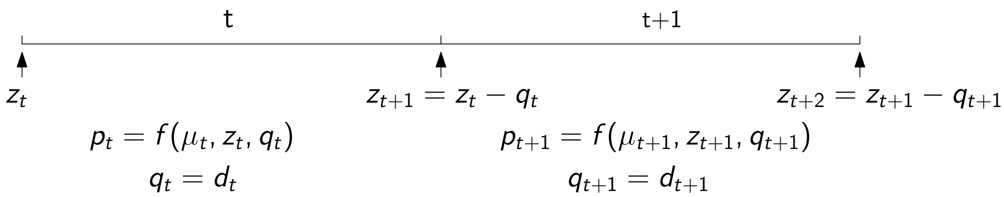
$$\varphi\sigma|z_{t+1}^X| + \varphi\sigma|z_{t+1}^Y|.$$

Market clearing. Let d_t^k denote the aggregate net liquidity demand in CCP k. Markets clear in each CCP and, therefore, $q_t^X = d_t^X$ and $q_t^Y = d_t^Y$. The key variables of the model along with the market clearing conditions are summarized in the time-line below:

[12] For tractability, we assume that liquidity traders do not bear collateral costs. In reality, however, they often do. In case they do, we believe that this would exacerbate the CCP basis as this will depress the price-sensitive liquidity flow. The reason is that that non-zero collateral cost will render some "arbitrage opportunities" too costly to pursue.

[13] We follow the notation of Foucault et al. (2013) and use $t+1$ to refer to the end of period t. The dealer has a long position in CCP k when $z_t^k > 0$. He has a short position when $z_t^k < 0$. In the case of IRS contracts, the dealer pays the fixed rate and receives the floating rate when $z_t^k > 0$.

[14] For standardized derivatives contracts, the margin models are fairly homogeneous across CCPs. We therefore use the same σ for both CCPs.



3.1 The dealer's problem

The change in the dealer's wealth during period t involves his current-period trade, the price change on his legacy positions, and the collateral cost. This wealth change, ω_{t+1}, is equal to:

$$\begin{aligned}\omega_{t+1} = & \underbrace{(p_{t+1}^X - p_t^X) z_{t+1}^X}_{\text{Marked-to-market value of } z_{t+1}^X} + \underbrace{(p_{t+1}^Y - p_t^Y) z_{t+1}^Y}_{\text{Marked-to-market value of } z_{t+1}^Y} - \underbrace{\varphi\sigma |z_{t+1}^X| - \varphi\sigma |z_{t+1}^Y|}_{\text{Total collateral cost}}, \\ = & (p_{t+1}^X - p_t^X)(z_t^X - q_t^X) + (p_{t+1}^Y - p_t^Y)(z_t^Y - q_t^Y) - \varphi\sigma |z_t^X - q_t^X| - \varphi\sigma |z_t^Y - q_t^Y|,\end{aligned} \tag{1}$$

where the per-contract marked-to-market value change of the contract cleared in CCP k is $p_t^k - p_{t-1}^k$ (i.e., the one-period gains or losses associated with that contract).

At time t the dealer maximizes, with respect to the quantity of contracts traded q_t^k, her wealth change. Being risk-neutral, the dealer solves:

$$\max_{q_t^X, q_t^Y} E[\omega_{t+1}]. \tag{2}$$

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

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

$$p_t^Y = \begin{cases} E_t[p_{t+1}^Y] + \varphi\sigma & \textit{if} \quad q_t^Y > z_t^Y \rightarrow z_{t+1}^Y < 0. \\ E_t[p_{t+1}^Y] & \textit{if} \quad q_t^Y = z_t^Y \rightarrow z_{t+1}^Y = 0. \\ E_t[p_{t+1}^Y] - \varphi\sigma & \textit{if} \quad q_t^Y < z_t^Y \rightarrow z_{t+1}^Y > 0. \end{cases} \tag{4}$$

3.2 Rational expectations equilibrium and the CCP basis

The dealer chooses the quantities q_t^k traded in each CCP given his current positions z_t^k, the prevailing market-clearing price p_t^k (which he takes as given), and the fundamental value μ_t. His price-contingent supply being equal to the price-contingent liquidity demand yields a unique market-clearing price. The quantities traded, embedded in z_{t+1}^k, and prices are therefore jointly determined. Proposition 1 summarizes the equilibrium result.

Proposition 1. ***Equilibrium prices in each CCP***

The linear equilibrium of the fragmented-clearing model is unique. The prices in CCP X and Y are:

$$\begin{bmatrix} p_t^X \\ p_t^Y \end{bmatrix} = \begin{cases} \boxed{\begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\varphi\sigma}{\delta - |(1-\delta)(2\pi-1)|} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} z_t^X \\ z_t^Y \end{bmatrix}} & \textit{if} \quad z_{t+1}^X z_{t+1}^Y < 0. \\ \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\varphi\sigma}{\delta} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} z_t^X \\ z_t^Y \end{bmatrix} & \textit{if} \quad z_{t+1}^X z_{t+1}^Y = 0. \\ \begin{bmatrix} \mu_t \\ \mu_t \end{bmatrix} - \frac{\varphi\sigma}{\delta} \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} z_t^X \\ z_t^Y \end{bmatrix} & \textit{if} \quad z_{t+1}^X z_{t+1}^Y > 0. \end{cases} \tag{5}$$

Proof. See Appendix.

As we are particularly interested in the case of an imbalance in natural flow across CCPs, we highlighted this case by putting it into a text box in Proposition 1. In the model, this is the case of the dealer position being of opposite sign across CCPs. The next proposition shows that this case indeed yields a non-zero basis.

Proposition 2. ***CCP basis***

The CCP basis, defined as the price differential across CCPs, is given by:

$$Basis_t \equiv p_t^Y - p_t^X = \begin{cases} \boxed{\dfrac{2\varphi\sigma}{\delta - |(1-\delta)(2\pi-1)|}(z_t^X - z_t^Y)} & \textit{if} \quad z_{t+1}^X z_{t+1}^Y < 0. \\ \frac{\varphi\sigma}{\delta} z_t^X & \textit{if} \quad z_{t+1}^X \neq 0, z_{t+1}^Y = 0. \\ -\frac{\varphi\sigma}{\delta} z_t^Y & \textit{if} \quad z_{t+1}^X = 0, z_{t+1}^Y \neq 0. \\ 0 & \textit{if} \quad z_{t+1}^X z_{t+1}^Y > 0 \ \textit{or} \ z_{t+1}^X = z_{t+1}^Y = 0. \end{cases} \tag{6}$$

Proof. The proof follows immediately from inserting the price expressions from Equation (5) into the price differential.

Proposition 2 yields two notable results. First, positions being non-zero is not a sufficient condition for the existence of a (non-zero) basis. In other words, a collateral cost in and of itself does not generate a basis. One needs the additional condition that the positions are of *opposite* sign across CCPs (i.e., there needs to be a netting opportunity across CCPs).

Second, in case there is a non-zero basis, the boxed expression in Proposition 2 shows what sign it should have and how its magnitude relates to the model parameters. The size of the basis *increases* in the wedge between dealer positions across CCPs ($|z_t^X - z_t^Y|$), the risk associated with the underlying (σ), the unit cost of collateral (φ), and the extent to which liquidity demand is imbalanced across CCPs (π). The size of the basis *decreases* in the proportion of price-sensitive liquidity traders (δ).

4 Empirical Analysis

4.1 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 used to price their derivatives contracts. These curves are obtained on a daily frequency for the full sample period and, as we explain in Section 4.2, 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 IRS, FRA and OIS contracts, in three main currencies (USD, EUR, and GBP). As mentioned before, all of these contracts belong to the same netting set, meaning that a position in one type of contract can be netted against an offsetting position in another contract.

The transaction-level 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.[15]

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.[16] Finally, we collect data on dealers' CDS spreads and balance sheet characteristics as well as data on short-term USD funding costs.

[15]We classify as dealers the financial institutions in 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`.

[16]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 `https://www.lch.com/risk-management/risk-management-ltd`.

4.2 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 of the 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.

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:

$$\sum_{i=1}^{2T} \frac{R_{k,t}^{fixed,6M,T}/2}{(1+\frac{R_{k,t,i}}{2})^i} = \sum_{j=1}^{4T} \frac{R_{k,t,j}^{floating,3M}/4}{(1+\frac{R_{k,t,j}}{4})^j} \tag{7}$$

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 six different swap maturities, namely for 2, 3, 5, 7, 10, and 30-year contracts and use the simple average of these maturity-specific bases for our empirical analysis:

$$\textbf{CME} - \textbf{LCH Basis}_t \equiv \frac{1}{6}\sum_T \left(R^{fixed,6M,T}_{CME,t} - R^{fixed,6M,T}_{LCH,t}\right) \tag{8}$$

In Figure 2 we plot the average CCP basis, over our sample period, on a weekly frequency. As one can see, the average basis fluctuates between 1bp and 3.5bps. Furthermore, it substantially increases from June 2015.[17]

The CME-LCH basis is economically significant. For example, for an indicative average basis of 1.7bps, 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.[18]

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

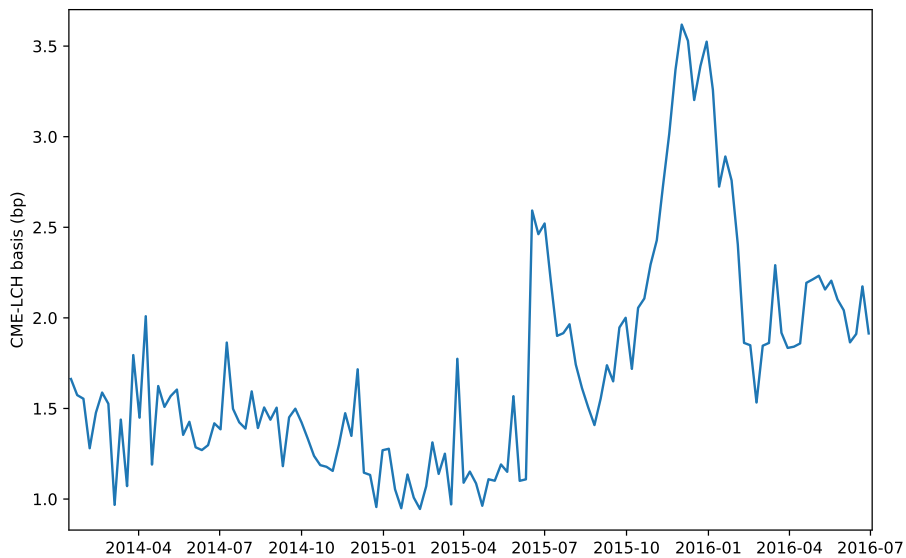
$$\textbf{CME} - \textbf{LCH Dealer Basis}^d_t \equiv R^{fixed,6M}_{CME,t} - \bar{R}^{fixed,6M,d}_{LCH,t} \tag{9}$$

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

[17] 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.

[18] 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: $1.7bps \times 10^{-4} \times \$48bn \times 9.7 \approx \$80mn$. A similar calculation shows that the cost to LCH net selling clients would be around \$3 million daily.

Figure 2: Average CME-LCH basis (in bps) in USD-denominated IRS contracts as defined in equation (8). The time period is Jan 2014-Jun 2016.



4.3 Hypotheses

Our model for the CCP basis gives rise to a number of testable hypotheses. Equation (6) shows that when dealers' outstanding inventories in each CCP are expected to be in the opposite direction (i.e., $z^X_{t+1}z^Y_{t+1} < 0$), 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 $z^X_t - z^Y_t$ 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 for 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.

Although our model does not explicitly capture the conflicts of interest that may arise between the shareholders and senior creditors of dealer-banks, the rationale articulated in Andersen et al. (2019) suggests that debt overhang should also affect the CCP basis. In particular, as the initial margin that a dealer pledges with CCPs is often funded with junior debt, a larger initial margin leads to an increase in the value of the dealer's senior debt and an associated decrease in the value of her equity. As a result, shareholders may seek to be compensated with a wider CCP basis. This effect is more pronounced when the dealer has higher credit risk, resulting in a positive relationship between dealer credit risk and the CCP basis.

Furthermore, given that longer-term contracts are riskier than shorter-term ones and attract a higher collateral cost, the above effects should be more pronounced for longer-maturity contracts than shorter-maturity ones.

Finally, our model suggests that if clients trade in a direction that minimizes (increases) dealers' imbalances, this will eventually 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 the amount of debt overhang faced by dealers' shareholders and as such is increasing with dealers' credit risk.*

H4: *The above effects are more pronounced for longer-maturity contracts than shorter-maturity ones.*

H5: *Dynamically, the CME-LCH basis is decreasing in the amount of client net buy volume in USD swap contracts cleared in LCH.*

4.4 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:

$$Basis_t = a + b \cdot Collateral_t + c \cdot Flex\_Ratio_t + d \cdot Libor\_Spread_t + u_t \tag{10}$$

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 (8).

Collateral captures the amount of collateral pledged by dealers and 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 expected Fed Funds rate which is calculated as:

$$Exp\_Fed\_Funds = 100 - Fed\_Funds\_Futures \tag{11}$$

  where $Fed\_Funds\_Futures$ is the 1-month Fed Funds futures price.

The absolute cumulative net volume transacted by dealers is a proxy for the size of the dealers' aggregate inventory imbalance and is included as a robustness check. This variable is noisy because we do not observe dealers' initial positions and also because it does not capture the riskiness of the underlying dealer positions.

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 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.[19] This variable also partially ameliorates the lack of data on dealer collateral and volumes cleared via CME.

Flex_Ratio is the fraction of volume traded by non-dealer banks and is used as a proxy for the presence of market participants who can clear flexibly in either CCP. This is because all banks in our sample have access (through their subsidiaries) to both LCH and CME and thus can in principle

[19]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.

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.

$Libor\_Spread$ is used to proxy the funding cost faced by the dealers. It is the difference between the one-month USD Libor and one-month Treasury Bill rates.

To test Hypothesis 4, we first calculate a difference in bases between long- and short-maturity contracts, which is defined as:

$$BasisDiff_t \equiv (Basis\_7Y_t + Basis\_10Y_t + Basis\_30Y_t) - (Basis\_2Y_t + Basis\_3Y_t + Basis\_5Y_t) \quad (12)$$

where $Basis\_XY_t$ is the time t basis of contracts with a maturity of X years. This variable effectively captures the difference in average bases for contracts with more and less than five years to maturity. This variable is then conditioned on the same set of variables as the CCP basis itself. As such, our model is:

$$BasisDiff_t = a + b \cdot Collateral_t + c \cdot Flex\_Ratio_t + d \cdot Libor\_Spread_t + u_t. \quad (13)$$

Table 1 shows summary statistics for the time-series variables used in the above specifications.

Table 1: Summary statistics of the variables used in specification (10). The aggregate CME-LCH basis (in bps) is the simple average of the maturity-specific bases defined in equation (8). *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 (11). *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 one-month USD Libor and one-month Treasury Bill rates. 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
BasisDiff (bps)	2.86	2.1	-0.45	8.68
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

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 non-dealer banks is anywhere between 20%-60% with an average of 34%.

Table 2 shows the estimation results of model (10). The predictions of our model are supported in the data with the key variables having the expected signs and most being statistically significant. The proxies for the amount of dealers' posted collateral - the amount of initial margin posted by dealers on LCH, the dealers' absolute cumulative net volume, and the expected Fed Funds rate - are positively associated with the CCP basis in most specifications.

The coefficient on the ratio of volume transacted with non-dealer banks is negative and significant, which is consistent with our model's intuition that location-flexible market participants will choose to clear where 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 also generally 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). In Section 4.6 we provide further evidence in support of the debt overhang hypothesis.

Overall, these results suggest that the CCP basis is fundamentally a reflection of dealers' collateral costs and at the same time a means of compensation against these costs as predicted by our model.

Table 3 shows the estimation results of model (13). The key explanatory variables maintain their signs and their significance (albeit with the exception of the expected Fed Funds rate), suggesting that the effects we identify are more pronounced for longer-maturity contracts than shorter-maturity ones. If our theory about the CCP basis is correct, this is to be expected since longer-maturity contracts are more collateral-intensive as a result of their higher sensitivity to interest rate risk.

4.5 Dynamic Effects on 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 5, 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 model with exogenous variables (VARX). Our model takes the following form:

$$\mathbf{y}_t = a + \sum_{i}^{3} (\mathbf{C}_i \mathbf{y}_{t-i} + d_i X_{t-i}) + u_t, \quad u \sim (\mathbf{0}, \Sigma) \tag{14}$$

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:

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

where IRS_Net_Vlm is the client net (i.e. buy minus sell) volume of USD-denominated IRS contracts, cleared in LCH. The rest of the endogenous variables are the same as the ones used in

Table 2: Estimation results of the basis time-series model (10). The dependent variable is the CME-LCH basis defined in equation (8). *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 (11) 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 one-month USD Libor and one-month Treasury Bill rates. Robust (Newey-West) t-statistics are in parentheses. *, ** and *** denote significance at 10%, 5% and 1% respectively. The time period is January 2014 to June 2016.

	(1) basis	(2) basis	(3) basis	(4) basis	(5) basis	(6) basis	(7) basis	(8) basis
IM	0.1406***					0.1279***		
	(4.36)					(4.05)		
AbsCumNetVlm		0.0002***					0.0001***	
		(4.40)					(3.13)	
Δ*Exp_Fed_Funds*			12.1029**					11.9232**
			(2.02)					(2.20)
Flex_Ratio				-1.9923***		-1.6224***	-1.7597***	-2.0373***
				(-3.58)		(-2.86)	(-2.95)	(-3.97)
Libor_Spread					5.6159***			
					(3.05)			
cons	0.1606	1.3944***	1.6923***	2.3990***	0.7926**	0.8524**	2.0569***	2.3803***
	(0.51)	(16.90)	(24.81)	(10.44)	(2.43)	(2.51)	(7.79)	(11.63)
R^2	0.174	0.061	0.074	0.094	0.166	0.235	0.132	0.170
N	130	130	128	130	130	130	130	128

Table 2 continued

	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	basis	basis	basis	basis	basis	basis	basis
IM	0.0836			0.1370***		0.0856	
	(1.28)			(4.95)		(1.47)	
AbsCumNetVlm		-0.0001			0.0002***		-0.0001
		(-0.67)			(3.81)		(-0.73)
Δ*Exp_Fed_Funds*			13.0969**	10.3304**	11.8070**	11.6295***	13.4078**
			(2.42)	(2.37)	(2.24)	(2.67)	(2.49)
Flex_Ratio	-1.5259***	-1.6640***	-1.6304***	-1.7398***	-1.8206***	-1.6085***	-1.6558***
	(-2.73)	(-3.08)	(-3.18)	(-3.19)	(-3.30)	(-3.03)	(-3.39)
Libor_Spread	3.0033	6.1087*	5.3471***			3.1939	6.4893**
	(0.98)	(1.85)	(3.21)			(1.17)	(2.10)
cons	0.8143***	1.4211***	1.3538***	0.7523**	1.9965***	0.7505**	1.3334***
	(2.72)	(2.91)	(3.52)	(2.41)	(8.65)	(2.61)	(3.21)
R^2	0.264	0.232	0.316	0.320	0.218	0.351	0.323
N	130	130	128	128	128	128	128

Table 3: Estimation results of the basis time-series model (13). The dependent variable is the difference between the long and short maturity bases defined in (12). *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 (11) 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 one-month USD Libor rate and the one-month Treasury Bill rate. Robust (Newey-West) 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)
	BasisDiff	BasisDiff	BasisDiff	BasisDiff	BasisDiff	BasisDiff	BasisDiff	BasisDiff
IM	0.6413***					0.5834***		
	(6.75)					(6.49)		
AbsCumNetVlm		0.0012***					0.0010***	
		(7.81)					(6.21)	
Δ*Exp_Fed_Funds*			15.1860					14.4029
			(0.87)					(0.90)
Flex_Ratio				-9.0724***		-7.3851***	-7.3957***	-8.8758***
				(-5.72)		(-4.61)	(-4.48)	(-5.72)
Libor_Spread					23.8095***			
					(4.09)			
cons	-4.2589***	0.6949***	2.8649***	5.9458***	-1.0769	-1.1101	3.4793***	5.8623***
	(-4.63)	(2.99)	(11.11)	(8.90)	(-1.06)	(-1.05)	(4.94)	(9.04)
R^2	0.306	0.226	0.010	0.166	0.252	0.413	0.332	0.167
N	130	130	128	130	130	130	130	128

Table 3 continued

	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	BasisDiff	BasisDiff	BasisDiff	BasisDiff	BasisDiff	BasisDiff	BasisDiff
IM	0.4243***			0.5978***		0.4174**	
	(2.64)			(6.45)		(2.47)	
AbsCumNetVlm		0.0005			0.0010***		0.0004
		(1.37)			(6.00)		(1.11)
Δ*Exp_Fed_Funds*			19.1656	7.4539	13.6666	12.0076	17.6074
			(1.35)	(0.67)	(1.04)	(1.10)	(1.32)
Flex_Ratio	-7.0382***	-7.1637***	-7.2248***	-7.5782***	-7.5034***	-7.1179***	-7.0977***
	(-4.67)	(-4.76)	(-5.02)	(-4.71)	(-4.63)	(-4.71)	(-4.86)
Libor_Spread	10.7865	14.7999	21.6987***			11.1949	15.9747*
	(1.38)	(1.57)	(3.89)			(1.42)	(1.67)
cons	-1.2469	1.9390	1.6968	-1.2398	3.4316***	-1.2461	1.7991
	(-1.28)	(1.53)	(1.41)	(-1.16)	(5.15)	(-1.23)	(1.50)
R^2	0.445	0.382	0.373	0.411	0.332	0.444	0.386
N	130	130	128	128	128	128	128

our time series regressions. *Libor_Spread* is treated as exogenous, as it is not affected by the other variables. 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 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 3 shows impulse response functions calculated from the estimated coefficients of model (14). 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 5. 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.

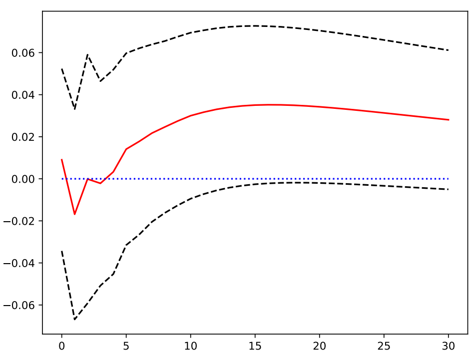
4.6 Dealer Effects

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

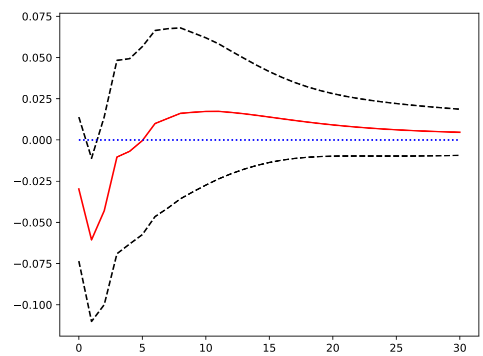
$$DealerBasis_{dt} = a + b \cdot Collateral_{dt} + c \cdot Flex\_Ratio_{dt} + d \cdot CreditRisk_{dt} + v_d + u_{dt}, \tag{15}$$

where d 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, $DealerBasis_{dt}$ is the dealer-specific CCP basis as defined in equation (9), $Collateral_{dt}$ is either the

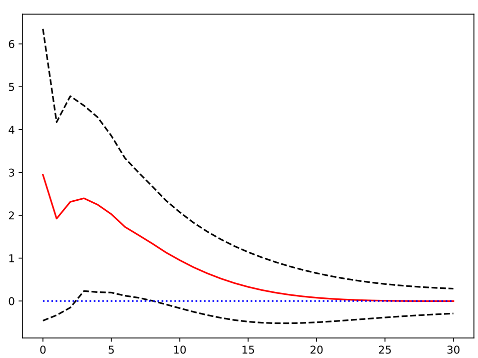
Figure 3: Impulse response functions obtained from estimating model (14). The CME-LCH basis is defined in equation (8). *IM* is the total initial margin posted by swap dealers on LCH, *Flex_Ratio* is the fraction of volume across all SwapClear products that dealers transact with non-dealer banks, *Libor_Spread* 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.



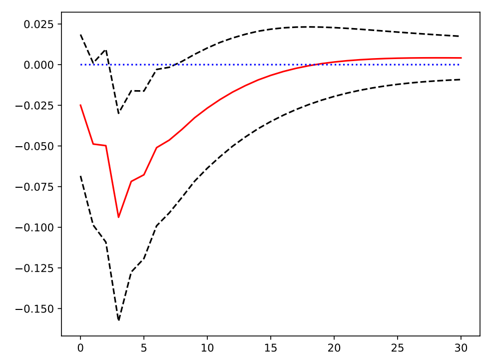
(a) Impact of *IM* on *Basis*



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



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



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

dealer-specific amount of initial margin posted with LCH or the absolute cumulative net volume traded by the dealer, and $Flex\_Ratio_{dt}$ is the dealer-specific 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, $CreditRisk_{dt}$ is either each dealer's 5-year CDS spread (or that of their parent company) or their equity ratio, defined as the market value of equity over the book value of assets. The model is estimated using dealer-specific fixed effect to account for unobservable, time-invariant, heterogeneity across dealers, as well as the time fixed effect.

Summary statistics for the panel variables used in the above specification are shown in Table 4. The average dealer-specific basis is around 1bps but fluctuates substantially and for some dealer-weeks also turns negative. On average, each dealer posts around 0.46 billion euro of collateral with SwapClear-LCH at any given week, but there is substantial variation across dealers-weeks with a minimum of around 10,000 euro and a maximum of 2.5 billion euro. 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 (15) are shown in Table 5. 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 debt overhang hypothesis in Andersen et al. (2019), 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, the equity holders of those dealer banks require a higher compensation, in the form of the CCP basis, to compensate the wealth transfer accruing to senior creditors, when additional collateral is posted to the clearing house.

5 Conclusion

With central clearing becoming a key feature of OTC derivatives markets after the 2007-2008 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

Table 4: Summary statistics, over dealer-weeks, of the variables used in specification (15). $DealerBasis_{it}$ is the dealer-specific CCP basis as defined in equation (9). *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 5-year 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

products is fragmented across multiple CCPs. In this context, we document an economically significant price differential between essentially identical USD interest-rate derivatives 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 canonical inventory model. 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 asset prices, is a fruitful area of further research and one with potentially important policy implications.

Table 5: Estimation results of the dealer basis panel model (15). The dependent variable is the proxy for the dealer-specific CME-LCH basis defined in equation (9). *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

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 prices (p_t^k) and the intrinsic value (μ_t) and is given by the expressions in the following table:

		$E_t[d_t^X]$	$E_t[d_t^Y]$
1.	$\mu_t \leq p_t^X < p_t^Y$	Δ	$-\Delta - \delta$
2.	$p_t^X < \mu_t < \frac{p_t^X+p_t^Y}{2}$	Δ	$-\Delta - \delta$
3.	$p_t^X < \mu_t = \frac{p_t^X+p_t^Y}{2}$	$\Delta + \frac{1}{2}\delta$	$-\Delta - \frac{1}{2}\delta$
4.	$\frac{p_t^X+p_t^Y}{2} < \mu_t < p_t^Y$	$\Delta + \delta$	$-\Delta$
5.	$p_t^X < p_t^Y \leq \mu_t$	$\Delta + \delta$	$-\Delta$
6.	$\mu_t < p_t^X = p_t^Y$	$\Delta - \frac{1}{2}\delta$	$-\Delta - \frac{1}{2}\delta$
7.	$p_t^X = p_t^Y = \mu_t$	Δ	$-\Delta$
8.	$p_t^X = p_t^Y < \mu_t$	$\Delta + \frac{1}{2}\delta$	$-\Delta + \frac{1}{2}\delta$
9.	$\mu_t \leq p_t^Y < p_t^X$	$\Delta - \delta$	$-\Delta$
10.	$\frac{p_t^X+p_t^Y}{2} < \mu_t < p_t^X$	$\Delta - \delta$	$-\Delta$
11.	$p_t^Y < \mu_t = \frac{p_t^X+p_t^Y}{2}$	$\Delta - \frac{1}{2}\delta$	$-\Delta + \frac{1}{2}\delta$
12.	$p_t^Y < \mu_t < \frac{p_t^X+p_t^Y}{2}$	Δ	$-\Delta + \delta$
13.	$p_t^Y < p_t^X \leq \mu_t$	Δ	$-\Delta + \delta$

where $\Delta \equiv \frac{1}{2}(1-\delta)(2\pi - 1)$.

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 X is $\Delta \equiv \frac{1}{2}(1-\delta)(2\pi-1)$ and in CCP Y is $-\Delta$. Price-sensitive order flow depends on the relationship between the midquotes and the fundamental value. There are three cases: (i) $p_t^X < p_t^Y$, (ii) $p_t^X = p_t^Y$, and (iii) $p_t^X > p_t^Y$.

When $p_t^X < p_t^Y$, μ_t could be (a) smaller than p_t^X, (b) larger than p_t^X but less than $(p_t^X + p_t^Y)/2$, (c) equal to $(p_t^X + p_t^Y)/2$, (d) larger than $(p_t^X + p_t^Y)/2$ but less than p_t^Y, or (e) larger than p_t^Y. In cases a and b, price sensitive traders will only sell in CCP B, since that gives the highest profit. Hence, their flow is zero in CCP X and $-\delta$ in CCP B. In case c, buying in CCP X or selling in CCP Y yield the same profit. In this special case, price sensitive traders will use their local CCPs, which are equally split. In other words, half of them buying in CCP X and the other half selling in Y. In cases d and e, buying in CCP X will lead to a higher profit. Price sensitive traders will only buy in CCP X, Hence, their flow will be δ in CCP X and zero in CCP Y. Exactly symmetric arguments apply when $p_t^X > p_t^Y$.

When $p_t^X = p_t^Y$, both CCPs lead to the same profit. Price sensitive traders will use their local CCPs. If μ_t is smaller (larger) than the midquotes, they will sell (buy). Hence, their flow will be $-\delta/2$ ($\delta/2$) in both CCPs. If μ_t is equal to the prices, they will not trade and the flows will be zero in both CCPs.

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:

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

In matrix form, this can be written as:

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

Taking expectations, this gives us:

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

From Lemma 1, we have the following order flow patterns for each inventory configuration:

		$E_t[d_t^X]$	$E_t[d_t^Y]$	z_{t+1}^X	z_{t+1}^Y
1.	$\mu_t \leq p_t^X < p_t^Y$	Δ	$-\Delta - \delta$	≤ 0	< 0
2.	$p_t^X < \mu_t < \frac{p_t^X + p_t^Y}{2}$	Δ	$-\Delta - \delta$	> 0	< 0
3.	$p_t^X < \mu_t = \frac{p_t^X + p_t^Y}{2}$	$\Delta + \frac{1}{2}\delta$	$-\Delta - \frac{1}{2}\delta$	> 0	< 0
4.	$\frac{p_t^X + p_t^Y}{2} < \mu_t < p_t^Y$	$\Delta + \delta$	$-\Delta$	> 0	< 0
5.	$p_t^X < p_t^Y \leq \mu_t$	$\Delta + \delta$	$-\Delta$	> 0	≥ 0
6.	$\mu_t < p_t^X = p_t^Y$	$\Delta - \frac{1}{2}\delta$	$-\Delta - \frac{1}{2}\delta$	< 0	< 0
7.	$p_t^X = p_t^Y = \mu_t$	Δ	$-\Delta$	$= 0$	$= 0$
8.	$p_t^X = p_t^Y < \mu_t$	$\Delta + \frac{1}{2}\delta$	$-\Delta + \frac{1}{2}\delta$	> 0	> 0
9.	$\mu_t \leq p_t^Y < p_t^X$	$\Delta - \delta$	$-\Delta$	< 0	≤ 0
10.	$\frac{p_t^X + p_t^Y}{2} < \mu_t < p_t^X$	$\Delta - \delta$	$-\Delta$	< 0	> 0
11.	$p_t^Y < \mu_t = \frac{p_t^X + p_t^Y}{2}$	$\Delta - \frac{1}{2}\delta$	$-\Delta + \frac{1}{2}\delta$	< 0	> 0
12.	$p_t^Y < \mu_t < \frac{p_t^X + p_t^Y}{2}$	Δ	$-\Delta + \delta$	< 0	> 0
13.	$p_t^Y < p_t^X \leq \mu_t$	Δ	$-\Delta + \delta$	≥ 0	> 0

There are now several different cases:
(I) when $z_{t+1}^X z_{t+1}^Y > 0$, the first order conditions of the dealer's problem in equations (3) and (4) imply:

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

This case corresponds to rows 1, 5, 6, 8, 9 and 13 in the above table. The order flow values in these rows exhibit the following patterns:

$$E_t[d_t^X] + E_t[d_t^Y] = \begin{cases} -\delta, & \text{if } z_{t+1}^X < 0, z_{t+1}^Y < 0 \\ \delta, & \text{if } z_{t+1}^X > 0, z_{t+1}^Y > 0 \end{cases}$$

From equation (A3) and the market clearing condition $d_t^i = q_t^i$, we have that:

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

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

$$\begin{bmatrix} E_t[p_{t+1}^X] - p_t^X \\ E_t[p_{t+1}^Y] - p_t^Y \end{bmatrix} = \begin{cases} \begin{bmatrix} -\varphi\sigma \\ \varphi\sigma \end{bmatrix}, & \text{if } z_{t+1}^X < 0, z_{t+1}^Y > 0 \\ \begin{bmatrix} \varphi\sigma \\ -\varphi\sigma \end{bmatrix}, & \text{if } z_{t+1}^X > 0, z_{t+1}^Y < 0 \end{cases} \tag{A4}$$

Again, using the values of the client order flows for this case (rows 2-4 and 10-12 in the above table) along with equation (A2) and the market clearing condition, we obtain:

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

(III) Finally, when $z_{t+1}^X z_{t+1}^Y = 0$ equations (3) and (4) imply:

$$\begin{bmatrix} E_t[p_{t+1}^X] - p_t^X \\ E_t[p_{t+1}^Y] - p_t^Y \end{bmatrix} = \begin{cases} \begin{bmatrix} -\varphi\sigma \\ 0 \end{bmatrix}, & \text{if } z_{t+1}^X < 0, z_{t+1}^Y = 0 \\ \begin{bmatrix} 0 \\ -\varphi\sigma \end{bmatrix}, & \text{if } z_{t+1}^X = 0, z_{t+1}^Y < 0 \\ \begin{bmatrix} \varphi\sigma \\ 0 \end{bmatrix}, & \text{if } z_{t+1}^X > 0, z_{t+1}^Y = 0 \\ \begin{bmatrix} 0 \\ \varphi\sigma \end{bmatrix}, & \text{if } z_{t+1}^X = 0, z_{t+1}^Y > 0 \\ \begin{bmatrix} 0 \\ 0 \end{bmatrix}, & \text{if } z_{t+1}^X = 0, z_{t+1}^Y = 0 \end{cases} \tag{A5}$$

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

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

Inserting the values of the estimated parameter vectors $\boldsymbol{\beta}$ in equation (A1) yields the expressions in (5) for prices.

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