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Market-Making Costs and Liquidity: Evidence from CDS Markets [*]

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ABSTRACT

In over-the-counter markets, dealers facilitate trading by becoming market makers. The costs dealers face, including the cost of holding inventory on balance sheet, and the ease, or difficulty, of reducing their positions, determine the degree of liquidity they provide. We provide a stylized model to examine the implications of these costs on dealer behavior and market liquidity. We use the model to guide an empirical study of the single-name credit default swap (CDS) market between 2010-2016. We find that transaction prices between dealers and clients have progressively become more dependent on the inventories of individual dealers rather than on the aggregate inventory across all dealers. We also find that the volume between clients and dealers decreases across all clients, with larger declines for clients that are depository institutions. At the same time, the volume of interdealer trades decreases, dealer inventories decline, and dealers with large inventories are more likely to trade with clients. Our results are consistent with the view that regulatory reforms implemented following the 2007-09 financial crisis increased the cost of holding inventory for dealers, and the cost of interdealer trading.

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Introduction

Liquidity – defined as the facilitation of the matching of buyers and sellers – is necessary for markets to function. In over-the-counter markets, dealers act as market makers and provide liquidity. As market makers, dealers enter into transactions with clients, and then try to balance their positions through offsetting transactions in the interdealer market, or through searching for contraposition clients. During this process, dealers face costs, stemming from the ease, or difficulty, of reducing their positions, and from the need to hold inventory on balance sheet.

In this paper, we explore how these market-making costs affect market liquidity by examining bid-ask spreads and trading volume. We study this question both theoretically and empirically. First, we propose a stylized model that assumes that dealers have some market power over their customers. In our model, an increase in the cost of holding inventory increases bid-ask spreads. Increases in the cost of transacting with other dealers also increases bid-ask spreads, but has additional consequences. When the cost of interdealer trading is low, dealers are able to hedge the risk of a transaction through trading with one another, and transaction prices between clients and dealers depend on the aggregate inventory of all dealers. On the other hand, when the cost of interdealer trading rises, dealers with large inventories are more likely to trade with clients and the bid-ask spreads between clients and dealers depend on the inventory of individual dealers. We also find that increased inventory costs reduce the volume of trading between dealers and clients, and, consequently, the volume between dealers, but that an increase in interdealer trading costs has a disproportionate effect on interdealer trading.

The intuition behind our model is simple. Consider the trade of a commodity among producers and consumers, facilitated by a network of dealers. An increase to the cost of intermediation across all dealers – for example, an increase in the storage cost of holding the commodity – would be passed to the producers and consumers, resulting in overall reduction in trading and production. On the other hand, a disruption to the network, for example due to the disappearance of some dealers, or an increase in transaction costs due to the elimination of trading routes, would limit risk sharing. Producers and consumers would be impacted if they had previously traded with dealers that were well connected but can no longer share the risk with other dealers.[1] For example, the exit of Drexel Burnham Lambert from the junk bond market in 1990, was shown to influence both the volume of trade and the price of assets – see Brewer & Jackson (2000).[2]

To test our model empirically, we consider a period that encompasses several regulatory reforms that, potentially, increased market-making costs for dealers. Following the 2007-09 financial crisis, the Basel 2.5 and Basel III accords were implemented, and the United States Congress passed the Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank Act), a wide-ranging reform of regulations for institutions and markets. Included among the reforms is a mandate that standardized swap contracts be centrally cleared; the Volcker rule, which places limits on dealer activity; increased margin requirements for bilateral transactions relative to centrally cleared ones; and increased capital requirements for bank-affiliated dealers.

We test whether there is evidence of deterioration in liquidity using data from the market for single-name credit default swaps (CDS) between 2010 and 2016.[3] The CDS market is a bilateral market intermediated by large dealers. Until the financial crisis, it was opaque – every firm had a record of its own transactions, but regulators had difficulty aggregating the information across firms. Since the financial crisis, in an effort to improve transparency, new rules have instituted reporting requirements for transactions. The availability of data on this OTC market; i.e., characteristics of CDS contracts, transactions, and positions of dealers and

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[1] Increased costs, or disruptions to existing networks, can be alleviated over time, with the entry of new market makers and the formation of new networks.

[2] Other examples include the impact of financial innovations on risk sharing. The introduction of reinsurance allowed insurance companies to more easily share risks. Similarly, securitization of mortgages allowed broader sharing of real estate risk. In both cases, the volume of trading increased.

[3] A credit default swap is a contract that insures an underlying bond, or a basket of bonds, against losses due to default.

clients, makes the CDS market a good candidate for testing for structural changes that may have influenced liquidity.

We formulate several hypotheses associated with how the financial reforms may have affected the market, both in terms of prices and in terms of volume. To determine whether the costs of interdealer transactions have increased, we test the dependence of bid-ask spreads on the inventory levels of individual dealers and on the aggregate inventory of all dealers. We find that at the beginning of our sample bid-ask spreads in transactions between dealers and clients depend on aggregate dealer inventory, not on the inventory of individual dealers. But later in our sample, bid-ask spreads do depend on the inventory of individual dealers, while the dependence on aggregate inventory weakens. This result suggests that, over time, interdealer costs have increased.

Consistent with both an increase in the cost of holding inventory and an increase in the cost of trading with other dealers, we find that the volume of transactions between dealers and clients has declined over time across all clients, with bigger declines for clients that are depository institutions. Consistent with an increase in the cost of interdealer transactions, we also find that dealer-to-dealer volume dropped by a much larger amount, and that, over time, dealers are more frequently transacting with clients, rather than other dealers, to offset large positions.

Overall, our results are consistent with both an increase in inventory costs and in the cost of transacting between dealers. The results are also consistent with the reforms having an impact on dealer behavior. Overall we find trading between dealers declines both in absolute and relative terms, dealer inventories drop, and bid-ask spreads transition from only depending on aggregate dealer inventory to also depending on individual dealer inventories.

Literature review

Our paper contributes to three separate strands of literature: on the market structure of bilateral markets and the behavior of dealers; the potential impact of the financial crisis reforms on market liquidity; and the empirical literature on inventory management and pricing by dealers, specifically for the single-name CDS markets.

The early literature on market microstructure addresses inventory management by dealers. Garman (1976), Stoll (1978), Amihud & Mendelson (1980), and Ho & Stoll (1983) propose models of dealer inventories and market microstructure. Reiss & Werner (1998) and Hansch, Naik & Viswanathan (1998) provide empirical evidence supporting the theoretical models using data from the London Stock Exchange. In the case of markets with competing dealers, Ho & Stoll (1983) show that if clients can costlessly transact with multiple dealers, dealers respond by adjusting their bid-ask spreads to attract client trades that reduce the dealers' inventories. In such models, all volume is concentrated between dealers and clients, and dealers avoid trading with other dealers. To explain the large volume in certain interdealer markets it becomes necessary to introduce frictions. Wang (2017) uses networks where trade is only possible among connected parties, and describes how core-periphery networks arise endogenously in over-the-counter markets as a trade-off between trade competition and market efficiency. Eisfeldt, Herskovic, Rajan & Siriwardane (2018) apply the structure of the CDS network to a network model of bilateral trading relationships driven by risk sharing and aversion to counterparty default risk. Without explicitly modeling the network of dealers and clients, we follow a similar approach. Clients are only allowed to trade with one dealer, while dealers are allowed to trade with other dealers as well.[4]

The early literature on the effect of regulation on dealer behavior focuses on the tradeoff between the potential reduction of externalities due to the regulation, and the potential increase in costs for the dealers, including the cost of holding inventory, opportunity cost, and the degree of competition – see (Benston & Smith 1976) and (Benston & Hagerman 1974). More recently, Duffie (2012) argues that the reforms following the financial crisis have the potential to adversely impact market liquidity, by increasing costs for dealers, which could

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[4] The assumption of clients being restricted to trade with one dealer, while allowing dealers to trade with each other, is also consistent with a higher search cost for clients, relative to dealers. See Duffie, Gârleanu & Pedersen (2005) and Lagos & Rocheteau (2009) for microstructure models with search costs and Rocheteau & Weill (2011) for an overview of the literature on market frictions and their implications for market liquidity.

indirectly impacting clients. Much of the recent empirical literature on the effect of regulatory reforms has focused on the over-the-counter secondary market for corporate bonds. Mizrach (2015) shows that, for the 1000 most actively traded bonds, the median daily turnover declined from 1.8 percent prior to the crisis – in 2005 – to approximately 1 percent in 2015. Mizrach (2015) also shows that between 2007 and 2013, trade size has decreased by 35 percent and the proportion of total volume traded in large blocks has declined by 15 percent. Bessembinder, Jacobsen, Maxwell & Venkataraman (2018) show that block trade volume for corporate bonds declines from 27 to 22 percent following the regulatory reforms, and trade size declines from \$3.2 million to \$1.8 million. They show that the decline is attributed to bank-affiliated dealers and argue that banking regulations are the likely cause. Dick-Nielsen & Rossi (2018), show that liquidity provision in corporate bonds has become significantly more expensive since the financial crisis, and attribute the increase to regulatory reforms. Bao, O'Hara & Zhou (2018) study the effect of downgrades on corporate bonds and find that illiquidity has increased after the implementation of the Volcker rule. Adrian, Boyarchenko & Shachar (2017) consider a much bigger dataset and show that institutions that face more regulations after the crisis reduce their overall bond trading volume and are less able to intermediate customer trades. A report by the Securities and Exchange Commission (2017) studies the evolution of the primary issuance of debt, equity, and asset-backed securities as well as market liquidity after the Dodd-Frank Act. The report finds mixed evidence about the impact of regulatory reforms on market liquidity. Specifically, for single-name CDS contracts, the report finds that the total number of participants have remained stable, while trade sizes, quoting activity and inter-dealer trade activity have declined. Not every paper finds that liquidity has declined. Using high-frequency trade and quote data for U.S. Treasury securities and corporate bonds, Adrian, Fleming, Shachar & Vogt (2017) find only limited evidence of a deterioration in market liquidity. Our paper focuses on the potential impact of regulatory reforms on CDS markets, and shows evidence that is consistent with an increased cost for dealers and reduced market liquidity.

Although the CDS market is relatively new, there is a growing literature on its structure. Shachar (2012) examines the determinants of liquidity provision by dealers in the market and finds that order imbalances of end users cause significant price impact, and that dealer inventories influence dealer willingness to intermediate. Collin-Dufresne, Junge & Trolle (2016) study differences between dealer-to-client and dealer-to-dealer transactions. They find evidence that dealer-to-client transactions have a higher average price impact than dealer-to-dealer transactions and that they Granger-cause dealer-to-dealer transactions, consistent with the interdealer market being used to manage inventory risk. Iercosan & Jiron (2017) further examine transaction costs in single-name CDS contracts and show that they are influenced by trading activity level, trading networks, and trading relationships. Du, Gadgil, Gordy & Vega (2016) consider the effect of counterparty risk on trading; i.e., the risk that a party to a CDS transaction might default at the time that the reference entity also defaults. They find that while counterparty risk has only a modest impact on the pricing of CDS contracts, it has a large impact on the choice of counterparties. D'Errico, Battiston, Peltonen & Scheicher (2017) consider the network of counterparties in the CDS market and show that it consists of dealers, risk sellers such as hedge funds, and risk buyers such as asset managers, with risk ending up in a few leading risk buyers with portfolios that show large exposures to potentially correlated reference entities. Boyarchenko, Costello & Shachar (2018) document that when single name CDS contracts become eligible for central clearing, globally systemically important institutions become more likely to use them, and that, in the aggregate, U.S. globally systemically important institutions reduce their exposure to corporate credit risk during the period of the implementation of financial reforms, primarily through reducing the amount of credit protection sold in the index CDS market. Our paper studies the evolution of CDS markets and shows that dealer behavior has changed over time, as dealers became subject to new regulations.

I. Background

We provide background on the CDS markets and highlight specific reforms that may have potentially influenced the behavior of CDS market participants – the Basel 2.5 and Basel III accords, rules requiring standardized financial contracts be cleared through central counterparties, the Volcker rule, the rules on margin requirements for bilateral transactions, and other rules, including the single counterparty credit limit rule.

A. CDS single-name market

The CDS market includes several segments. The largest segments are CDS indices, CDS single-name contracts, and CDS contracts on sovereigns. Single-name credit default swaps are contracts that insure against losses on a bond of a corporate issuer, following the issuer's default. Each contract has an associated maturity. If the company does not default before the maturity of the contract, the CDS contract expires worthless.[5]

CDS markets developed in the early 1990s and grew substantially in the run-up to the 2007-09 financial crisis. Participants in the single-name CDS market include clients and dealers. Clients include depository institutions, insurance companies, and investment companies, such as hedge funds and investment funds. Clients may buy CDS contracts to hedge exposure to the default of a corporation, they may buy or sell CDS contracts to speculate on potential default, or use CDS contracts as potentially cheaper substitutes to holding corporate bonds.

Dealers make markets in CDS contracts by buying and selling them as a service to clients. They may also trade with other dealers to hedge existing positions. Dealers may also use CDS contracts to hedge their corporate bond holdings.

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[5] There are several additional features of single-name CDS contracts. For example, many CDS contacts include a coupon, paid by the buyer to the seller, as long as the underlying corporation is not in default.

B. Basel accords

The Basel accords form a set of recommendations for regulations in the banking industry. Adoption of the accords by regulators worldwide imposes several requirements on CDS dealers. The Basel 2.5 and Basel III banking accords recommend minimum capital requirements, leverage, liquidity, net stable funding ratio, and countercyclical requirements with respect to regulatory capital, leading to increased costs for dealers – see BCBS & IOSCO (2013) for more information. These regulatory constraints apply to all CDS dealers, as all firms are affiliated with financial institutions that are subject to the accords. However, while Basel 2.5 and Basel 3 took effect in June 2012 and July 2013, respectively, not all of the changes were immediately implemented in the United States.

C. Central clearing of standardized swap contracts

Central counterparties (CCPs) have assumed a key role in clearing over-the-counter derivatives as a result of regulatory reforms since the financial crisis. In a centrally cleared market, parties to a derivatives contract enter into two back-to-back contracts with the CCP that offset one another.

Major swap participants and private funds active in the swaps market were required to begin clearing major index CDS that they entered into on or after March 11, 2013. Though single-name CDS have not been mandated to be cleared, nearly all of the single-name reference entities that are included in an index are eligible to be cleared. Netting positions through CCPs reduces offsetting transactions in the interdealer market. As of June 2018, the only CCP in the single-name CDS market in the United States is ICE Clear Credit.

D. Volcker rule

Section 619 of the Dodd-Frank Act, commonly referred to as the "Volcker rule," restricts U.S. depository institutions with \$50 billion in assets and depository institutions with \$10 billion in assets and \$1 billion in tradable assets, from engaging in proprietary trading. Generally, this is interpreted as a restriction on U.S. depository institutions making speculative investments within their own accounts, or owning stakes in hedge funds and private equity funds. Based on the criteria described in the Volcker rule, all dealers trading CDS contracts written on bonds issued by U.S. companies are subject to the Volcker rule.

While the Dodd-Frank Act became law in July 2010, writing the Volcker rule and its implementation took several years. The Financial Stability Oversight Council issued a recommendation in January 2011, and a Federal Register proposal appeared in November 2011. The final regulation was issued two years later, in December 2013. The final regulation required covered institutions to calculate measures of risk management, sources of revenue, customer-facing activity, and comprehensive profit and loss, starting April 1, 2014. These measures are reported to supervisors beginning July 1, 2014.

While the Volcker rule does permit "market-making-related" trading as long as position taking is "designed not to exceed the reasonably expected near term demands of clients, customers or counterparties," determining the intent behind a trade is difficult. The rule specifies several measures that covered institutions must calculate and report, including client-facing activity and volume of transactions. The rule has been criticized as confusing, cumbersome to implement, and resulting in increased market-making costs, dealer exit, and reduced market liquidity. In a report issued in June 2017, the U.S. Treasury "recommends significant changes to the Volcker Rule," to eliminate "undue compliance burdens" – see Mnuchin & Phillips (2017*a*) and Mnuchin & Phillips (2017*b*). The first fine for violating the rule was issued to Deutsche Bank AG in April 2017. The \$19.7 million fine was based on the bank's admission to the Federal Reserve in March 2016 that the bank lacked adequate systems for monitoring activities that might be subject to the Volcker rule.

E. Margin requirements for bilateral transactions

The financial reforms that followed the 2007-09 financial crisis mandated margin requirements for non-centrally cleared derivatives with two objectives: reduction of systemic risk, and promotion of central clearing. Only standardized derivatives are suitable for central clearing, so a substantial fraction of derivatives, totaling hundreds of trillions of dollars in notional amounts, are not cleared through a central counterparty. To avoid the systemic contagion and spillover risks that materialized during the financial crisis, margin requirements for non-centrally cleared derivatives are set to ensure that collateral is available to offset losses caused by the default of a derivatives counterparty. In addition, margin requirements on non-centrally cleared derivatives, are set to promote central clearing, in line with the G-20 2009 reform program.

Two types of margin requirements exist: variation margin and initial margin. Variation margin reflects the daily change in market value of the financial instruments. Two counterparties must exchange variation margin to cover their current exposure based on the valuation of the financial instruments they are trading. These daily valuations, also known as "mark-to-market," follow transparent and well recognised industry methodologies. The rules for exchanging variation margin apply to trades between the largest market participants since September 1, 2016 in the United States, Canada, and Japan.

Initial margin is the amount of collateral that investors post to enable trading in financial instruments. Posting initial margin aims to reduce the broker's exposure to the investor's credit risk. While there is a common process for derivatives that are traded and cleared in exchanges, this is largely a new process for uncleared OTC derivatives. The obligation to post initial margin became effective on September 1, 2016 in the United States, Canada and Japan for a few of the largest market participants. The obligation to post initial margin for most other entities follows a phased-in implementation calendar between September 1, 2017 and September 1, 2020.

F. Other regulatory reforms

In addition to the reforms we already mentioned, even reforms that have not been implemented as of this date may influence risk-taking by dealers. For example, section 165(e) of the Dodd-Frank Act, directs the Federal Reserve Board to prescribe regulations that limit single counterparty credit exposure to a percentage of tier 1 capital. The Federal Reserve Board adopted the final rule on June 19, 2018 regulation YY, subpart H. Globally systemically important banks are required to comply by January 1, 2020, and all other firms by July 1, 2020. Dealers may act in advance of regulations being implemented, making it difficult to pin down a specific date when their behavior changes.

II. Model

The literature in market microstructure suggests that when clients can costlessly choose between dealers, and dealers are competitively pricing contracts, the resulting equilibrium is a market where dealers with unbalanced inventories set their bid and ask prices to attract clients that can help rebalance their inventories, and where dealers do not trade with each other – see Ho & Stoll (1983) and Madhavan & Smidt (1993). To obtain interdealer trading, we must introduce a friction between dealers and clients. With such a friction, dealers set bid and ask spreads to maximize an objective, and hedge the risk of contracts acquired by clients by trading.

We assume that the friction is that the dealer is a monopolist with respect to his clients. We also assume that, at least some of, the client volume is noise-trading; i.e., clients are not better informed than dealers. In addition, the dealer's inventory is subject to position limits. Dealers also face an inventory cost when their position is larger, or smaller, than their preferred position. The limits and inventory cost can reflect, for example, credit constraints or increasing capital requirements for larger dealer inventories. Tighter limits can also be thought to correspond to larger inventory costs.[6]

We quantify the impact of increasing the cost of trading between dealers or the dealers' inventory cost by considering a highly stylized model. While the model cannot match the quantitative features of the data, it can provide useful, qualitative, comparative statics.

In the model, we assume that the dealer has a preferred inventory of m contracts, and that the position limits are $m-1$ and $m+1$ contracts. The payoff of each contract is D, where $E(D) = \mu$. We assume that the payoff occurs in the next period and that the dealer maximizes expected utility of next period's wealth. We also assume that, if the dealer's inventory is either at level $m+1$ or level $m-1$, the dealer faces an inventory cost c_i.

A client may arrive and trade one unit with the dealer at a price set by the dealer. The dealer sets an ask price, p_{ask}, to sell an additional contract to the client, and a bid price, $p_{\text{bid}} < p_{\text{ask}}$, to buy an additional contract from the client. These prices affect the probability of arrival of a client. We assume that the probability that a client will want to buy a contract at the dealer's ask price; i.e., the probability that the dealer will sell a contract, is

$$\pi_{\text{sell}} = \frac{\lambda_{\max} - p_{\text{ask}}}{\lambda_{\max}},$$

where we assume that $\lambda_{\max} \geq p_{\text{ask}} \geq \mu$. The probability that a client will want to sell a contract at the dealer's bid price; i.e., the probability that a dealer will buy a contract, is

$$\pi_{\text{buy}} = \frac{p_{\text{bid}} - \lambda_{\min}}{\lambda_{\min}},$$

where we assume that $\lambda_{\min} \leq p_{\text{bid}} \leq \mu$. We assume that the probability that more than one client will want to trade is zero. In addition, we assume that the values of $\lambda_{\min}, \lambda_{\max}$, are such that the probabilities $\pi_{\text{buy}}, \pi_{\text{sell}} \leq 0.5$.

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[6] Using data from the NYSE, Comerton-Forde, Hendershott, Jones, Moulton & Seasholes (2010) find that financing constraints do influence the behavior of liquidity providers – when inventories are large, spreads widen when specialists have large positions, or when they lose money.

If the dealer can trade with other dealers, he may temporarily violate his position limits by trading with a client, and, immediately after trading with the client at the posted price, trade away the surplus contract by trading with the other dealers. We assume that a dealer can trade with other dealers, but that a client can only trade with one dealer.

We abstract away from modeling the interactions between dealers. Instead, we assume that a dealer can trade with other dealers at two prices: either sell at a network selling price, $p_{n,s}$, or buy at a network buying price, $p_{n,b}$. We also assume that the difference between the network buying and selling prices is a function of the aggregate inventory of all dealers.[7]

The dealer's bid and ask prices towards his clients are set to maximize the dealer's expected wealth. The dealer's wealth is given by

$$W = \begin{cases} \pi_{\text{buy}}(-p_{\text{bid}} + mD) & \\ \quad +\pi_{\text{sell}} \max(p_{\text{ask}} + (m-1)D - c_i - p_{n,b}, p_{\text{ask}} + mD - 2p_{n,b}) & \text{initial inventory} = m-1, \\ \quad +(1-\pi_{\text{buy}}-\pi_{\text{sell}}) \max((m-1)D - c_i, mD - p_{n,b}) & \\ \pi_{\text{buy}} \max(-p_{\text{bid}} + (m+1)D - c_i, -p_{\text{bid}} + mD + p_{n,s}) & \\ \quad +\pi_{\text{sell}} \max(p_{\text{ask}} + (m-1)D - c_i, p_{\text{ask}} + mD - p_{n,b}) & \text{initial inventory} = m, \\ \quad +(1-\pi_{\text{buy}}-\pi_{\text{sell}})mD, & \\ \pi_{\text{buy}} \max(-p_{\text{bid}} + (m+1)D - c_i, -p_{\text{bid}} + mD - p_{n,s}) & \\ \quad +\pi_{\text{sell}}(p_{\text{ask}} + mD) & \text{initial inventory} = m+1. \\ \quad +(1-\pi_{\text{buy}}-\pi_{\text{sell}}) \max((m+1)D - c_i, mD + p_{n,s}), & \end{cases} \tag{1}$$

Dealer wealth takes into account the dealer's ending inventory, inventory costs, and the possibility that the dealer may reduce inventory to the dealer's preferred position by trading with other dealers. For each initial inventory level, Equation (1) captures the possible trades and ending inventory levels. For example, if the initial inventory is at the dealer's preferred level, m, then the dealer will buy another contract with probability π_{buy} for a new inventory of

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[7] This assumption is supported by theoretical models in the literature that consider networks of dealers, e.g., see Eisfeldt et al. (2018).

$m+1$ contracts, with payoff $-p_{\text{bid}}+(m+1)D-c_i$, or sell a contract with probability π_{sell} for a new inventory of $m-1$ contracts, with payoff $p_{\text{ask}}+(m-1)D-c_i$, or, not transact, and stay with the initial inventory of m contracts, with payoff mD. If it increases his wealth, the dealer may also choose to reduce his ending position by trading with other dealers and either paying, or receiving, the corresponding network price.

The resulting bid-ask spreads depend on the cost of trading with the other dealers; i.e., the network buying and selling prices. We distinguish two cases. First, if the trading cost with other dealers is small, in particular if $p_{n,s} > \mu - c_i$, and $p_{n,b} < \mu + c_i$, then the dealer always offloads excess inventory to the network, and sets the bid and ask prices to be equal to

$$\begin{aligned} p_{\text{bid}} &= \frac{\lambda_{\min} + p_{n,s}}{2}, \\ p_{\text{ask}} &= \frac{\lambda_{\max} + p_{n,b}}{2}. \end{aligned} \tag{2}$$

We note that, in this case, the bid-ask spread depends on the aggregate inventory of the dealers rather than the inventory of the dealer that actually transacts with a client.

In the second case, when the cost of trading with other dealers is large, i.e., if $p_{n,s} < \mu - c_i$, and $p_{n,b} > \mu + c_i$, then the dealer does not transact with the other dealers in the network. Instead, the dealer's wealth next period is given by

$$W = \begin{cases} \pi_{\text{buy}}(-p_{\text{bid}} + mD) + (1-\pi_{\text{buy}})((m-1)D - c_i), & \text{initial inventory} = m-1, \\ \pi_{\text{buy}}(-p_{\text{bid}} + (m+1)D - c_i) & \\ \quad +\pi_{\text{sell}}(p_{\text{ask}} + (m-1)D - c_i) & \text{initial inventory} = m, \\ \quad +(1-\pi_{\text{buy}}-\pi_{\text{sell}})mD, & \\ \pi_{\text{sell}}(p_{\text{ask}} + mD) + (1-\pi_{\text{sell}})((m+1)D - c_i), & \text{initial inventory} = m+1, \end{cases} \tag{3}$$

Since, in this case, trading with other dealers is too expensive, when the initial inventory is at the dealer's upper or lower position limit, the dealer sets the bid and ask prices to guarantee that the final inventory does not violate these limits; i.e., $p_{\text{ask}} = \lambda_{\max}$, when the initial inventory level is $m-1$, and $p_{\text{bid}} = \lambda_{\min}$, when the initial inventory level is $m+1$. The bid and ask prices are given by:

$$\begin{aligned} p_{\text{bid}} &= \frac{\lambda_{\min} + \mu - c_i}{2} \leq \mu \leq \lambda_{\max} = p_{\text{ask}}, && \text{initial inventory} = m-1, \\ p_{\text{bid}} &= \frac{\lambda_{\min} + \mu - c_i}{2} \leq \mu \leq \frac{\lambda_{\max} + \mu + c_i}{2} = p_{\text{ask}}, && \text{initial inventory} = m, \\ p_{\text{bid}} &= \lambda_{\min} \leq \mu \leq \frac{\lambda_{\max} + \mu + c_i}{2} = p_{\text{ask}}, && \text{initial inventory} = m+1. \end{aligned} \tag{4}$$

Figure 1: Model Bid-Ask Spreads

Note: Bid-ask spreads for the case of a dealer that faces large inventory and interdealer trading costs and does not trade with other dealers are shown in vertical, solid, lines, while bid-ask spreads for a dealer that is able to trade with other dealers are shown in vertical, dashed, lines.
Source: Authors' calculations.

Figure 1 illustrates the different bid-ask spreads. When the cost of trading with other dealers is small, the dealer's bid-ask spread does not depend on his initial inventory, but does depend on the aggregate dealer inventory; cheap interdealer trading allows for greater risk-sharing and the dealer can offer a bid-ask spread that is narrower than in the case when the network trading costs are large. On the other hand, when, due to high interdealer trading costs, the dealer does not engage in interdealer trading, the bid-ask spread does depend on the dealer's initial inventory. In this case, the bid-ask spread is the narrowest when the dealer's initial inventory is at his preferred level, while it increases as the inventory moves to the position limits.[8]

Our model has implications on the trading volume between a dealer and his clients, as well as between dealers. When the interdealer trading cost is low, trading volume is given by

$$\begin{aligned}
\text{Dealer-client volume} &= \frac{p_{n,s}-\lambda_{\min}}{2\lambda_{\min}} + \frac{\lambda_{\max}-p_{n,b}}{2\lambda_{\max}} \\
\text{Dealer-dealer volume} &= \begin{cases} 1+\frac{p_{n,s}-\lambda_{\min}}{2\lambda_{\min}} + \frac{\lambda_{\max}-p_{n,b}}{2\lambda_{\max}}, & \text{initial inventory} = m-1, \\ \frac{p_{n,s}-\lambda_{\min}}{2\lambda_{\min}} + \frac{\lambda_{\max}-p_{n,b}}{2\lambda_{\max}}, & \text{initial inventory} = m, \\ 1+\frac{p_{n,s}-\lambda_{\min}}{2\lambda_{\min}} + \frac{\lambda_{\max}-p_{n,b}}{2\lambda_{\max}}, & \text{initial inventory} = m+1, \end{cases}
\end{aligned} \tag{5}$$

When the interdealer trading cost is high, interdealer volume is zero, and trading volume is given by

$$\begin{aligned}
\text{Dealer-client volume} &= \begin{cases} \frac{\mu-c_i-\lambda_{\min}}{2\lambda_{\min}}, & \text{initial inventory} = m-1, \\ \frac{\mu-c_i-\lambda_{\min}}{2\lambda_{\min}} + \frac{\lambda_{\max}-\mu+c_i}{2\lambda_{\max}}, & \text{initial inventory} = m, \\ \frac{\lambda_{\max}-\mu+c_i}{2\lambda_{\max}}, & \text{initial inventory} = m+1, \end{cases} \\
\text{Dealer-dealer volume} &= 0
\end{aligned} \tag{6}$$

Our model has several empirically testable implications for market-making costs and liquidity. First, if interdealer trading costs are low, bid-ask spreads between dealers and clients depend on the aggregate inventory of all dealers; when interdealer costs are high, bid-ask

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[8] The same result; i.e., that the bid-ask spread widens with the size of the dealer's inventory, is shown by Amihud & Mendelson (1980). Other models, without position limits, do not arrive at this result. For example, Ho & Stoll (1981), consider an objective function that accounts for the variance of the value of the portfolio, but do not include position limits. They find that both the bid and ask the prices change by an amount that depends on the riskiness of the payoff of a contract and the inventory level, but that the bid-ask spread remains the same.

spreads between dealers and clients depend on the inventory of individual dealers instead. Increased, aggregate, inventory costs lead to the reduction of volume, both between dealers and clients and between dealers. If interdealer costs are high enough, the reduction in interdealer trading is much greater. In that case, dealers with large inventories become more likely to trade with clients, rather than other dealers. We explore these predictions empirically in Section IV.

III. Data Description and Summary Statistics

We test our model with data from the market for single-name CDS contracts on reference entities that are U.S. domiciled corporations. We examine the period from January 2010 to November 2016. We use several datasets. One dataset includes CDS transactions and positions, another dataset includes price information for CDS contracts, and a third dataset includes information on bond transactions.

The CDS dataset is a regulatory dataset provided by the Depository Trust & Clearing Corporation (DTCC).[9] DTCC provides trade processing services for most major dealers in CDS markets. After a trade is registered with DTCC, it is recorded into the Trade Information Warehouse (TIW). The part of the TIW that we have access to includes information on all standardized and confirmed CDS transactions involving U.S. entities since 2010 and reported to DTCC; i.e., transactions that involve a U.S. counterparty or a U.S. reference entity. The dataset also includes weekly information on outstanding positions between counterparties. Reported positions represent the accumulation of all past reported transactions between the counterparties. All counterparties are identified in the data set. Approximately 10% of transcactions include the credit spread at which the transaction took place.[10] The total number of reference entities with senior-tier debt is 1032, while the total number of dealers is 32. In

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[9] The CDS data in this paper are confidential in nature and are provided to the Office of Financial Research (OFR) by The Depository Trust & Clearing Corporation.

[10] We compare transactions with pricing information to transactions without in the Appendix.

addition, we collect information on the volume of index CDS contracts that we use as controls in our models.

To enhance the TIW dataset, we use data from Markit Group Ltd. to capture market-wide CDS price information. Markit provides CDS spreads for a variety of maturities and seniorities of the referenced underlying corporate bonds. Additionally Markit provides base currencies and International Swap Dealer Association (ISDA) default documentation clauses. We use the most liquid maturity of five years, senior reference obligations, U.S. dollar-denominated contracts, and average over all ISDA default documentation clauses. We use expected default recovery rates reported by Markit for each reference entity and each corporate bond underlying the contract. In addition, we use the Markit dataset to implicitly determine the date that CDS contracts on a reference entity become eligible for central clearing. The date is set to be the first time we either observe a transaction between a dealer and the CCP on the reference entity, or when the reference entity becomes part of a CDS index.

In cases where the DTCC dataset provides information on the spread for a specific CDS transaction, or an upfront payment, we estimate the transaction spread. By comparing the transaction spread to the Markit credit spread, one can determine whether the buyer or the seller initiate the transaction. If the transaction spread is above the Markit spread, we assume the buyer initiated the transaction. If it is below, we assume the seller initiated the transaction. That is, we consider the difference between the Markit credit spread and the DTCC transaction spread to represent the bid-ask spread for the specific transaction.[11] In addition, we determine whether a transaction is dealer- or client-initiated, based on which side paid the implied bid-ask spread.[12]

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[11] In the case where an upfront payment is reported, we use the R implementation of ISDA's conventional model to convert the upfront fee to a par spread. The same methodology in used in Iercosan & Jiron (2017). Similar to our use of the Markit credit spread to calculate the bid-ask spread of a specific transaction, Iercosan & Jiron (2017) define the execution cost of a transaction using the CDS par spread relative to the end-of-day CDS consensus par spread from Markit.

[12] Our definition of bid-ask spread corresponds to half of the round-trip cost of buying and selling the same contract.

Finally, in addition to the TIW and Markit datasets, we use the Financial Industry Regulatory Authority's regulatory Trade Reporting and Compliance Engine (TRACE) dataset that includes information on corporate bond transactions. Unlike the TIW dataset, not all counterparties are identified in this dataset. We use TRACE to map CDS contracts to the underlying corporate bonds, and to calculate the volume of trading for the underlying corporate bond.

Table I presents summary statistics for the single-name CDS market from 2010 through 2016. The variables are averaged monthly and the data are presented for each year in our sample. We note that the average number of dealers and average dealer gross notional per reference entity declined during the period. While the average number of clients and number of client trades per reference entity changed relatively little, the average monthly volume between clients and dealers declined. The biggest decline occurred in the average monthly market volume, which dropped by more than 90 percent, mostly due to the decline in the average monthly volume in dealer-to-dealer trades, which dropped by more than 95 percent. Consistent with the decline in the number of dealers, the number of clients per dealer has increased. Consistent with the decline in the volume between dealers, the number of dealer counterparties for each dealer; i.e., the number of other dealers each dealer trades with, has declined. Finally, the number of dealers each client trades with remained stable, and the number of clients each dealer trades with increased.

Figure 2 presents the distribution of the number of dealers with non-zero trading volume in each single-name reference entity for each year in our data. The figure illustrates a decline in the number of dealers across all reference entities.[13]

Table II presents summary statistics for the number of clients, trades, trade size, volume, net notional, and gross notional, per reference entity by type of client, averaged monthly.

Table III presents information on transaction prices, averaged annually. We note that CDS spreads, measured in basis points, have dropped over time, while the bid-ask spreads, mea-

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[13] We have found that, on average, it is the smaller dealers that are dropping out from trading each reference entity.

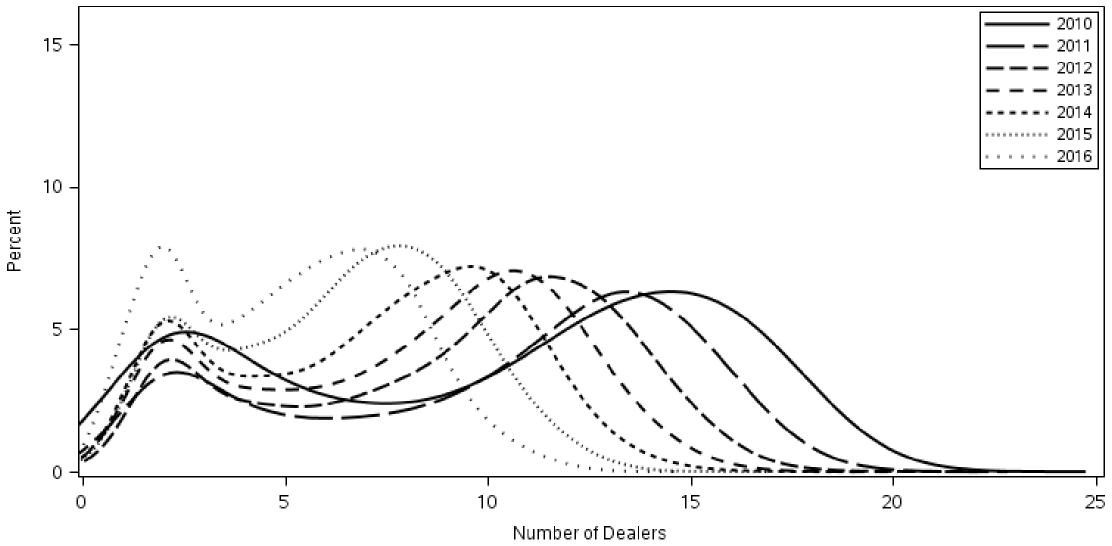
Table I: Monthly CDS Market Statistics per Single-name Reference Entity

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
# of Dealers	10.1	10.1	9.1	8.1	7.2	6.4	5.2
	(0.9)	(4.8)	(4.1)	(3.8)	(3.4)	(2.9)	(2.7)
# of Clients	4.3	5.2	5.3	4.5	4.3	4.1	4.4
	(0.6)	(6.5)	(6.8)	(6.3)	(5.9)	(5.2)	(4.9)
# of Clients per Dealer	1.8	1.9	1.8	1.9	2.0	2.0	2.3
	(1.8)	(1.9)	(1.4)	(1.8)	(2.3)	(1.9)	(2.1)
# of Dealer Counterparties per Dealer	1.8	1.8	1.6	1.5	1.5	1.4	1.3
	(1.4)	(1.3)	(1.1)	(0.9)	(0.8)	(0.6)	(0.5)
# of Dealers per Client	1.2	1.3	1.2	1.3	1.3	1.3	1.3
	(0.3)	(0.4)	(0.4)	(0.5)	(0.4)	(0.4)	(0.4)
Volume	2,350.6	935.5	639.0	463.2	372.1	192.6	134.9
	(1886.9)	(5878.0)	(1380.9)	(927.9)	(701.4)	(316.3)	(305.9)
Interdealer Volume	2,262.3	770.5	530.6	373.4	282.9	127.4	72.1
	(1885.4)	(1761.5)	(1267.2)	(826.5)	(605.6)	(264.3)	(270.6)
Client Volume	88.2	165.0	108.4	89.8	89.2	65.2	62.8
	(18.8)	(5585.8)	(227.3)	(179.2)	(174.6)	(108.8)	(103.6)
# of Trades	177.2	140.2	106.6	81.1	69.1	42.0	38.9
	(28.9)	(213.3)	(161.5)	(122.2)	(106.0)	(58.5)	(50.0)
# of Interdealer Trades	160.4	122.0	82.6	59.7	47.4	22.7	14.0
	(27.3)	(199.9)	(138.1)	(90.5)	(71.2)	(30.0)	(28.3)
# of Client Trades	16.8	18.2	24.0	21.4	21.8	19.3	25.0
	(2.8)	(32.9)	(45.6)	(47.3)	(50.1)	(42.2)	(36.4)
Interdealer Fraction of Trade	0.82	0.82	0.79	0.80	0.78	0.69	0.50
	(0.07)	(0.21)	(0.23)	(0.23)	(0.25)	(0.30)	(0.36)
Dealer Net Notional	-17.5	-32.5	-20.8	-20.4	-24.9	-42.7	-35.4
	(20.5)	(263.7)	(243.6)	(195.2)	(180.0)	(133.7)	(101.1)
Dealer Gross Notional	7,151.0	7,510.8	7,003.4	5,210.8	3,649.6	2,716.0	1,962.4
	(974.6)	(9407.0)	(9369.0)	(7181.4)	(5267.3)	(3847.9)	(2946.4)

Note: Volume, net notional, and gross notional reported in millions
Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation.

sured as a percentage, are relatively stable. The increase in the percentage of client-dealer trades reflects the decline in interdealer volume. We note that, as expected, the implied bid-ask spread for transactions between dealers and clients that are dealer-initiated is lower, on average, compared to the implied bid-ask spread for transactions that are client-initiated for every year in the data other than 2011.

Figure 2: Number of Dealers per Single-name Reference Entity



Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation.

Table II: Monthly CDS Market Statistics per Single-name Reference Entity by Client Type

	Depository Institutions	Investment Company	Insurance & Pension	Other
# of Clients	0.34	3.41	0.16	0.08
	(0.52)	(3.86)	(0.22)	(0.13)
# of Trades	0.78	15.56	0.32	0.20
	(1.49)	(22.87)	(0.54)	(0.38)
Trade Size	1.55	4.84	1.09	0.40
	(3.54)	(6.78)	(3.43)	(0.85)
Volume	5.56	69.67	2.09	1.06
	(16.99)	(213.69)	(4.90)	(2.76)
Net Notional	14.02	2.20	6.85	4.63
	(53.60)	(45.16)	(49.34	(8.12)
Gross Notional	77.51	109.02	35.62	28.16
	(115.26)	(115.52)	(58.24)	(61.99)

Note: Trade size, volume, net notional, and gross notional reported in millions
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

IV. Empirical Study

We identify and test several hypotheses related to the model. The hypotheses revolve around the impact of an increased cost of holding inventory and of trading with other dealers. First, we

Table III: Transaction Price Statistics

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
CDS Spread (bps)							
Client Trade - Client Initiated	49.62	34.34	32.22	54.79	15.03	14.33	26.45
	(112.09)	(63.20)	(90.87)	(185.12)	(76.43)	(37.03)	(101.38)
Client Trade - Dealer Initiated	49.31	35.55	33.61	55.64	15.90	14.67	27.93
	(112.47)	(67.25)	(92.80)	(203.26)	(84.75)	(43.78)	(105.71)
Interdealer Trade	64.93	35.21	42.66	74.26	12.68	15.23	26.97
	(138.36)	(67.44)	(111.07)	(219.81)	(61.87)	(40.35)	(84.04)
Implied Bid-Ask Spread (%)							
Client Trade - Client Initiated	4.30	3.99	3.96	4.81	4.26	4.52	5.90
	(3.72)	(3.49)	(3.45)	(4.27)	(3.39)	(3.71)	(4.22)
Client Trade - Dealer Initiated	4.58	4.36	3.68	4.25	3.62	3.57	4.92
	(4.10)	(4.09)	(3.54)	(4.22)	(3.34)	(3.21)	(4.30)
Interdealer Trade	5.13	4.83	4.50	5.65	4.49	5.57	5.63
	(4.27)	(4.14)	(3.78)	(4.44)	(3.59)	(4.16)	(3.60)
Proportion of Transactions (%)							
Client Trade - Client Initiated	13.94	14.13	19.54	20.47	21.43	21.78	24.85
Client Trade - Dealer Initiated	11.68	9.50	11.98	12.83	12.36	12.85	16.02
Interdealer Trade	74.37	76.37	68.48	66.70	66.21	65.38	59.13

Note: The CDS spread is the daily average Markit CDS spread, measured in basis points. The bid-ask spread is calculated by finding the distance that a transaction occurs at, relative to the daily Markit CDS spread and is presented as a percentage of the daily Markit CDS spread. Information is presented for both interdealer and client-dealer transactions. Client-dealer transactions are separated to client-initiated ones and dealer-initiated ones based on which side paid the the implied bid-ask spread. We present the proportion of priced transactions observed by type.
Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation and Markit Group Ltd.

test whether there has been an impact on individual transaction bid-ask spreads; i.e., whether bid-ask spreads shift from depending more on aggregate dealer inventories to depending more on individual dealer inventories over time. Second, we test whether volume between dealers and between dealers and clients has been affected. In particular, whether the volume of dealer-to-dealer transactions has decreased and whether dealers with large inventories trade more with clients. Third, we examine whether dealer inventories have declined. Finally, we examine whether client volume has declined.

A. Transaction spreads are impacted by individual dealer inventory levels

When the cost of interdealer trading is low, dealers are able to engage in transactions with clients and then easily share the resulting risk with other dealers in the interdealer market. In that case, our model suggests that the bid-ask spread of individual transactions between clients and dealers should depend more on the aggregate inventory of dealers, and less on the inventory of the individual dealer involved in the transaction. As the cost of interdealer trading increases, dealers reduce their reliance in the interdealer market, resulting in bid-ask spreads in dealer to client transactions that depend more on the inventory of individual dealers.

We consider both dealer-to-dealer and dealer-to-client transactions. We use the difference between the price reported in the DTCC data and the price reported in Markit as a measure of the bid-ask spread of a transaction.[14]

First, we regress the bid-ask spread in transactions between dealers on the inventory of the buyer and the seller on contracts on the same reference entity, on the total amount of CDS contracts outstanding, and on the aggregate dealer inventory. We perform this regression by separating data into two periods, before and after a specific date - the *separating date*. To capture changes over time we use different dates to separate the data, varying them annually from the end of 2010 to the end of 2015.

$$\begin{aligned}\text{Interdealer bid-ask spread}_{j,l} =& \beta_0 + \beta_1 \text{Buyer inventory}_{j,l} + \beta_2 \text{Buyer inventory}_{j,l} \times i_{\text{sep}} \\ &+ \beta_3 \text{Seller inventory}_{j,l} + \beta_4 \text{Seller inventory}_{j,l} \times i_{\text{sep}} \\ &+ \beta_5 \text{CDS outstanding}_{j,l} + \beta_6 \text{Aggregate dealer inventory}_{j,l} \\ &+ \beta_7 \text{Aggregate dealer inventory}_{j,l} \times i_{\text{sep}} + \varepsilon, \\ &\text{sep} \in \{12/31/2010, 12/31/2011, \ldots, 12/31/2015\}.\end{aligned} \tag{7}$$

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[14] Iercosan & Jiron (2017) measure the execution cost of a transaction in the same way.

where j is the index for the underlying reference entity, l is the index of the transaction, and i_{sep} is a dummy variable that is equal to zero before a separating date, and one afterwards.

The regression results for Equation (7) are provided in Table IV. The coefficients are reported in basis points per billion dollars. The columns correspond to the different separating dates: 12/31/2010, 12/31/2011, ..., 12/31/2015. The table confirms that aggregate dealer inventory is a significant determinant of spreads: an increase of aggregate inventory by $1 billion increases spreads by 135-168 basis points before the separating date. Following the date separating the data in two, an increase of the aggregate inventory by $1 billion increases spreads by a further 5-84 basis points – an indication of increased interdealer transaction costs.[15] For all separating dates, buyer and seller inventories are largely insignificant before the separating date. The impact on bid-ask spreads is larger and somewhat more significant after the separating date.

We also test the hypothesis by regressing the bid-ask spread in transactions between dealers and clients on the individual dealer inventory on contracts on the same reference entity, on the total amount of CDS contracts outstanding, and on the aggregate dealer inventory. We follow the same strategy of using different separating dates, as in Equation (7).

$$\begin{aligned}\text{Dealer-client bid-ask spread}_{j,l} = &\beta_0 + \beta_1 \text{Dealer inventory}_{j,l} + \beta_2 \text{Dealer inventory}_{j,l} \times i_{\text{sep}} \\ &+ \beta_3 \text{CDS outstanding}_{j,l} + \beta_4 \text{Aggregate dealer inventory}_{j,l} \\ &+ \beta_5 \text{Aggregate dealer inventory}_{j,l} \times i_{\text{sep}} \\ &+ \beta_6 \text{Dealer Initiated Trade}_{j,l} + \varepsilon \\ &\text{sep} \in \{12/31/2010, 12/31/2011, \ldots, 12/31/2015\}.\end{aligned} \tag{8}$$

The regression results for Equation (8) are provided in Table **??**. The coefficients are reported in basis points per billion dollars. The table confirms that aggregate dealer inventory is a significant determinant of spreads before the separating date and that its significance de-

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[15] The impact before the separating date is given by the coefficient of the Aggregate dealer inventory variable, while the coefficient after the separating date is measured by adding the coefficients of the Aggregate dealer inventory variable and the Aggregate dealer inventory variable × i_{sep} variable.

Table IV: Interdealer Bid-Ask Spread

sep	2010	2011	2012	2013	2014	2015
Intercept	1384.0^{*}	1382.6^{*}	1382.7^{*}	1381.7^{*}	1380.9^{*}	1383.0^{*}
	(633.8)	(634.2)	(634.3)	(634.3)	(634.2)	(634.3)
Buyer Inventory	40.6^{***}	11.9	13.5^{*}	9.80	10.6	11.4
	(7.50)	(6.23)	(6.04)	(5.97)	(5.93)	(5.92)
Buyer Inventory * i_{sep}	-70.2^{***}	-4.82	-44.0	73.5	102.0	-6.29
	(12.1)	(19.2)	(28.3)	(38.9)	(60.7)	(82.6)
Seller Inventory	10.9	-4.43	1.13	3.40	4.32	5.85
	(8.27)	(6.51)	(6.29)	(6.21)	(6.16)	(6.15)
Seller Inventory * i_{sep}	-10.5	80.9^{***}	73.3^{**}	61.9	85.1	-210.7^{*}
	(12.3)	(19.1)	(28.3)	(38.5)	(62.7)	(88.9)
CDS Outstanding	0.06	0.09	0.09	0.09	0.09	0.10
	(0.088)	(0.088)	(0.088)	(0.088)	(0.088)	(0.088)
Aggregate Dealer Inventory	135.5^{***}	165.8^{***}	166.6^{***}	166.6^{***}	168.2^{***}	168.0^{***}
	(5.37)	(4.60)	(4.55)	(4.50)	(4.50)	(4.49)
Aggregate Dealer Inventory * i_{sep}	69.7^{***}	12.2	20.1	30.5^{*}	83.5^{***}	4.98
	(6.33)	(10.09)	(12.07)	(14.10)	(20.78)	(32.05)
Reference Entity Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.08	0.08	0.08	0.08	0.08	0.08
Obs	93,492	93,492	93,492	93,492	93,492	93,492

Note: Coefficients for buyer inventory, seller inventory, and aggregate dealer inventory are reported in basis points per billion dollars.
Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation and Markit Group Ltd.

creases over time: an increase of aggregate inventory by $1 billion increases spreads by 34-49 basis points before the separating date, followed by a decrease by 14-30 basis points after. Individual dealer inventory, on the other hand, is an insignificant variable before the separating date, but becomes significant after. During the later years in our sample, after the separating date, as dealer inventories increase, bid-ask spreads decrease, an indication that dealers make an effort to attract clients to reduce their existing exposures, rather than trade with other dealers. We also note that dealer-initiated trades have bid-ask spreads that are approximately 25 basis points lower than client-initiated trades.

The results of both regressions are consistent with the assumption that inventory costs and the costs of trading with other dealers increase over time. The bid-ask spreads for inter-

Table V: Dealer-Client Bid-Ask Spread

sep	2010	2011	2012	2013	2014	2015
Intercept	1637.9	1641.5	1639.8	1646.6	1640.9	1630.2
	(825.4)	(825.2)	(825.3)	(825.2)	(825.1)	(825.0)
Dealer Inventory	-20.52	-10.85	-6.15	-6.75	-7.14	-6.94
	(12.198)	(9.320)	(8.744)	(8.358)	(8.133)	(8.078)
Dealer Inventory * i_{sep}	4.66	-25.76	-73.53^{***}	-133.81^{***}	-316.71^{***}	-510.84^{***}
	(16.065)	(18.012)	(21.492)	(28.147)	(42.402)	(53.347)
CDS Outstanding	0.28^{**}	0.27^{**}	0.29^{***}	0.29^{***}	0.30^{***}	0.30^{***}
	(0.095)	(0.095)	(0.095)	(0.095)	(0.095)	(0.095)
Aggregate Dealer Inventory	42.99^{***}	49.06^{***}	38.25^{***}	36.32^{***}	34.85^{***}	34.08^{***}
	(7.134)	(5.728)	(5.291)	(5.097)	(4.980)	(4.927)
Aggregate Dealer Inventory * i_{sep}	-14.14^{*}	-29.62^{***}	-15.49^{***}	-14.93^{**}	-15.73^{**}	-16.76^{*}
	(6.547)	(5.194)	(4.955)	(5.201)	(6.273)	(7.693)
Dealer Initiated Trade	-25.2^{***}	-25.3^{***}	-25.0^{***}	-25.0^{***}	-25.2^{***}	-25.2^{***}
	(4.344)	(4.343)	(4.343)	(4.342)	(4.341)	(4.340)
Reference Entity Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.02	0.02	0.02	0.02	0.02	0.02
Obs	76,766	76,766	76,766	76,766	76,766	76,766

Note: Coefficients for dealer inventory, and aggregate dealer inventory are reported in basis points per billion dollars.

Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation and Markit Group Ltd.

dealer transactions increase over time, while the bid-ask spreads for dealer-client transactions decrease.

B. The volume of transactions between dealers declines

We test the hypothesis in several ways. First, we calculate the Quandt Likelihood Ratio (QLR) statistic based on the time variation of the coefficients of the indicator variables of the following regressions:

$$
\begin{aligned}
\text{Perc. interdealer trade}_{j,t} = {} & \beta_0 + \beta_1 \log(\text{Dealer-Client Volume}_{j,t}) \\
& + \beta_2 \text{CDS spread}_{j,t} + \beta_3 \Delta\text{CDS spread}_{j,t} \\
& + \beta_4 \text{Recovery rate}_{j,t} + \beta_5 \log(\text{Dealer-Dealer Index Volume}_t) \\
& + \beta_6 \log(\text{Bond Volume}_{j,t}) \\
& + \beta_7 i^{j}_{\text{Clearing}} + \beta_8 i_{\text{sep}} + \varepsilon
\end{aligned} \tag{9}
$$

The variable on the left-hand side, Perc. interdealer $\text{trade}_{j,t}$ is the percentage of the volume of interdealer trades in reference entity j, during time period t, measured against the volume for all trades. The right-hand side variables are: Dealer-Client $\text{Volume}_{j,t}$ is the aggregate volume of trades between all dealers and all clients in reference entity j during time period t; CDS $\text{spread}_{j,t}$, and ΔCDS $\text{spread}_{j,t}$ are the spread and the change in spread for the CDS five-year contract for reference entity j at time period t; Recovery $\text{rate}_{j,t}$ is the expected recovery rate for the CDS five-year contract for reference entity j at time period t; Dealer-Dealer Index Volume_t is the aggregate volume between dealers on index CDS contracts during period t – it controls for potential shifts between the single-name and index CDS contracts; Bond $\text{Volume}_{j,t}$ is the aggregate volume on bonds issued by reference entity j during period t; i^{j}_{Clearing} is an indicator variable that, for each reference entity j, is equal to zero for every period before that reference entity is eligible to be centrally cleared, and one afterwards – it captures the potential shift in demand that may occur with the introduction of central clearing for a reference entity.[16]

The indicator variable, i_{sep}, separates the data into two periods, before and after a separating date. We shift the time period for the separating date between an early and a late date in the data, and perform one regression for each value across reference entities and dealers. For each regression we calculate the F-statistic for the model with the separating date indicator variable

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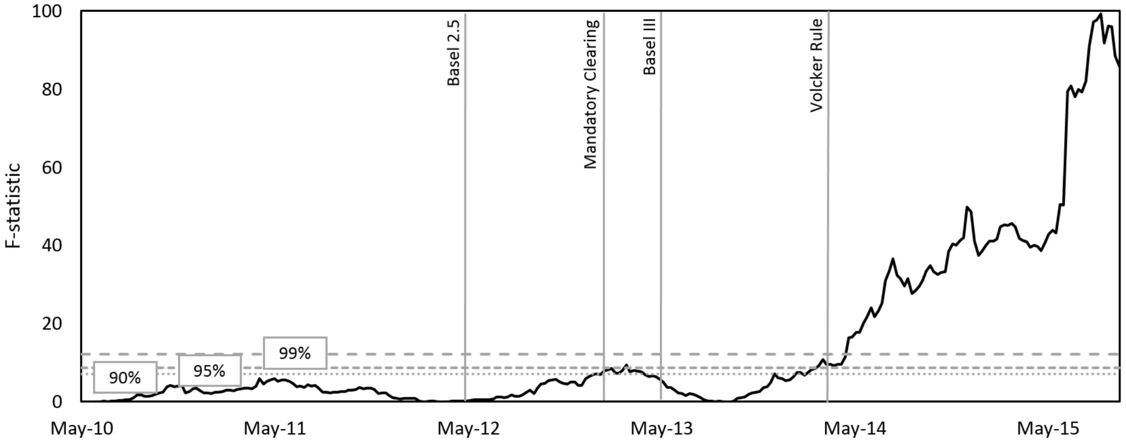
[16] If a reference entity is not eligible to clear across the entire period, we omit this indicator variable from the regression.

vs. a model without an indicator variable. An increasing value of the F-statistic, as the period corresponding to the separating date changes, indicates a structural break in the percentage of interdealer trade.

Figure 3 shows the results of the QLR test for Equation (9). The vertical axis shows the F-statistic between a model with the indicator variable separating the two periods and a model without, where standard errors are clustered by time. In this figure, the separating date varies weekly. The test shows that there is a structural break in the percentage of interdealer trade. The onset occurs during the early summer of 2014.

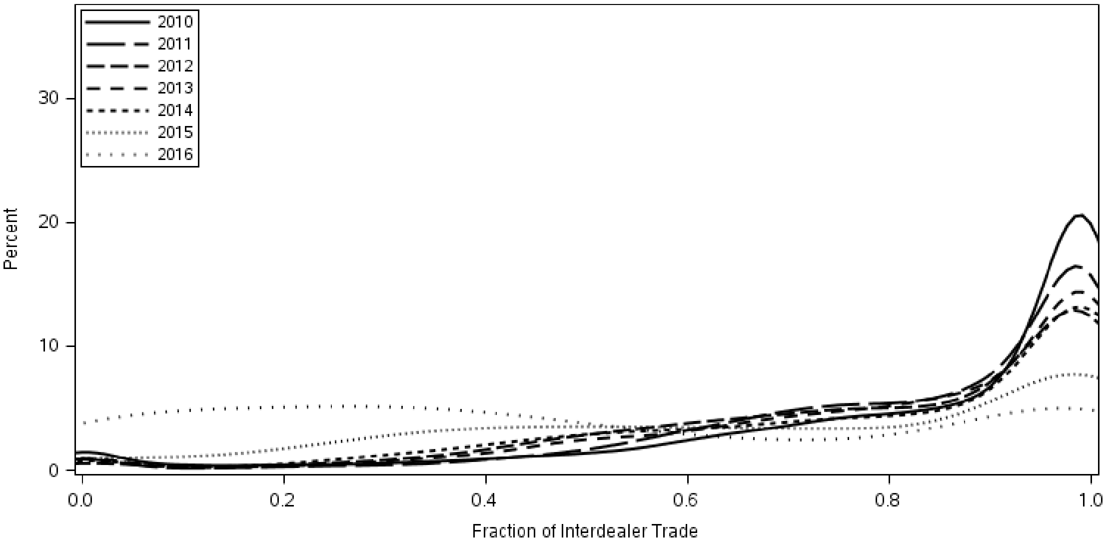
Figure 3: QLR Test on Percentage of Interdealer Trading Volume



Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation, Markit Group Ltd., and the Financial Industry Regulatory Authority.

Figure 4 shows the distribution of the percentage of interdealer trading volume, relative to total volume, for each month and reference entity for each year in our data. The figure illustrates that the proportion of interdealer trading volume has been declining. The largest change occurs between 2014 and 2015. Until 2014, interdealer volume accounted for the majority of total volume in most reference entities; after 2015, cases where interdealer volume was a large percentage of total volume became less common.

Figure 4: Annual Fraction of Interdealer Trades Across Single-name CDS



Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation.

The regression results for Equation (9), where the separating date variable corresponds to the end of 2010, 2011, etc., are provided in Table VI. The table confirms the results in Figure 4. Interdealer volume, measured as a percentage of total volume in a reference entity, decreases when dealer-to-client volume increases, increases when CDS spreads increase, and increase when dealer-to-dealer volume of index CDS contracts and bond volume increases. The introduction of voluntary clearing for each single-name CDS contract is only marginally significant for 2010 and 2011. Accounting for all these variables, we find that there has been a significant decrease of the percentage share of interdealer volume over time – in particular during the last 3 years in the data.[17]

When the cost of transacting with other dealers increases, our model predicts that aggregate interdealer trading declines, and that individual dealers are less likely to trade with other dealers. If the transaction cost increases as a function of a dealer's inventory, then the decline in interdealer trading also depends on dealer inventory levels.

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[17] We note that trading in CDS contracts is highly seasonal. The seasonality is due to the regular issuance of new series of CDS indices. When a new series is issued, several market participants roll over their existing positions, driving up the volume. We use seasonal indices to account for seasonality in the regressions.

Table VI: Weekly fraction of Interdealer Trades across Single-name CDS

sep	2010	2011	2012	2013	2014	2015
log(D-C Volume)	-0.15^{***}	-0.15^{***}	-0.15^{***}	-0.15^{***}	-0.16^{***}	-0.16^{***}
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
CDS Spread (5 Y)	0.30^{***}	0.30^{***}	0.31^{***}	0.30^{***}	0.37^{***}	0.37^{***}
	(0.04)	(0.041)	(0.041)	(0.040)	(0.043)	(0.042)
Δ CDS Spread (5 Y)	-0.15	-0.16	-0.17	-0.15	-0.18	-0.2
	(0.101)	(0.102)	(0.102)	(0.099)	(0.108)	(0.116)
Recovery Rate	0.10	0.11^{*}	0.10	0.10	0.09	0.04
	(0.050)	(0.051)	(0.051)	(0.051)	(0.051)	(0.051)
log(D-D Index Volume)	0.03^{***}	0.03^{***}	0.03^{***}	0.03^{***}	0.03^{***}	0.03^{***}
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
log(Bond Volume)	0.18^{***}	0.17^{***}	0.19^{***}	0.14^{***}	0.11^{***}	0.13^{***}
	(0.013)	(0.015)	(0.023)	(0.017)	(0.013)	(0.013)
i_{Clearing}	-0.01^{*}	-0.02^{*}	-0.02^{**}	-0.01	0.00	-0.01
	(0.007)	(0.007)	(0.007)	(0.007)	(0.006)	(0.007)
i_{sep}	-0.02	-0.02	0.02	-0.07^{**}	-0.16^{***}	-0.18^{***}
	(0.014)	(0.015)	(0.024)	(0.022)	(0.020)	(0.020)
Seasonal Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.21	0.21	0.21	0.21	0.23	0.23
Obs	48,383	48,383	48,383	48,383	48,383	48,383

Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation, Markit Group Ltd., and the Financial Industry Regulatory Authority.

Figure 5 investigates this question. The figure illustrates inventory management practices by dealers. The left panel shows how dealer positions change over a week over different time periods.[18] In line with results in the microstructure literature for other markets – see Hansch et al. (1998) for the case of equity markets – the figure shows that dealers tend to decrease their inventories when they deviate from a net zero position. The right panel sheds additional light on how this reduction is achieved. While dealer-to-dealer transactions are the most common for all inventories over all time periods, over time dealers are relatively more likely to try to reduce their inventories by trading with clients. This behavior becomes more pronounced the further away the inventories are from zero, and is consistent with the predictions of our stylized model when the interdealer trading cost increases over time, and as a function of a dealer's inventory.

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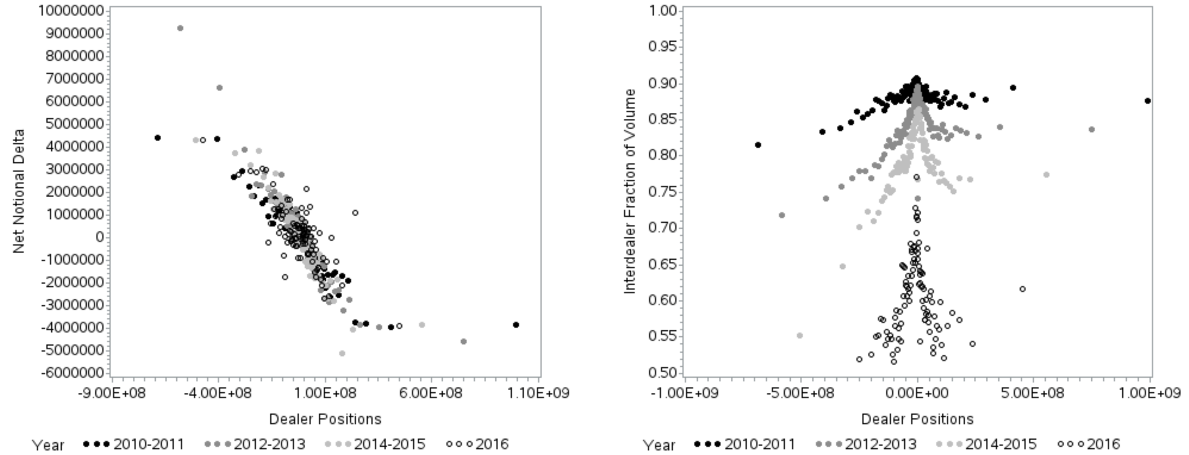
[18] Each dot corresponds to a centile of the distribution of net positions in each reference entity for each week.

Figure 5: Dealer Inventory Control



(a) Weekly Dealer-by-Dealer Inventory vs. Inventory Change

(b) Dealer use of the Interdealer market vs. trading with Clients

Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation.

We also investigate the time variation of interdealer trading at the level of individual dealers, by rerunning the regression model in Equation (9). Rather than aggregate across all dealers, as in Equation (9), we model interdealer trading at the level of individual dealers and reference entities.

$$\begin{aligned}\text{Perc. interdealer trade}_{i,j,t} = {} & \beta_0 + \beta_1 \log(\text{Dealer-Client Volume}_{i,j,t}) \\ & + \beta_2 \log(|\text{Dealer Inventory}_{i,j,t}|) + \beta_3 \text{CDS spread}_{j,t} \\ & + \beta_4 \Delta\text{CDS spread}_{j,t} + \beta_5 \text{Recovery rate}_{j,t} \\ & + \beta_6 \log(\text{Dealer-Dealer Index Volume}_t) \\ & + \beta_7 \log(\text{Bond Volume}_{j,t}) + \beta_8 i^{j}_{\text{Clearing}} + \beta_9 i_{\text{sep}} + \varepsilon, \\ & \text{sep} \in \{12/31/2010, 12/31/2011, \ldots, 12/31/2015\}.\end{aligned} \tag{10}$$

Table VII presents the results of the regression models in Equation (10). We note that, while significant, the decline at the individual dealer level is smaller than in the aggregate level.

Table VII: Weekly fraction of Interdealer Trades across Single-name CDS and Dealer

sep	2010	2011	2012	2013	2014	2015
log(D-C Volume)	-0.08^{***}	-0.08^{***}	-0.08^{***}	-0.08^{***}	-0.08^{***}	-0.08^{***}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
log(|Dealer Inventory|)	0.04^{***}	0.04^{***}	0.04^{***}	0.04^{***}	0.04^{***}	0.04^{***}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
CDS Spread (5 Y)	0.41^{***}	0.41^{***}	0.42^{***}	0.41^{***}	0.45^{***}	0.47^{***}
	(0.06)	(0.06)	(0.062)	(0.06)	(0.064)	(0.066)
Δ CDS Spread (5 Y)	-0.11	-0.11	-0.11	-0.11	-0.12	-0.13
	(0.113)	(0.113)	(0.117)	(0.112)	(0.119)	(0.132)
Recovery Rate	0.02	0.02	0.02	0.03	0.03	0.01
	(0.032)	(0.032)	(0.032)	(0.032)	(0.033)	(0.034)
log(D-D Index Volume)	0.01^{***}	0.01^{***}	0.01^{***}	0.01^{***}	0.01^{***}	0.01^{***}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
log(Bond Volume)	0.04^{***}	0.05^{***}	0.06^{***}	0.04^{***}	0.02^{***}	0.03^{***}
	(0.004)	(0.005)	(0.006)	(0.004)	(0.003)	(0.003)
i_{Clearing}	-0.04^{***}	-0.04^{***}	-0.04^{***}	-0.04^{***}	-0.03^{***}	-0.03^{***}
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
i_{sep}	0.00	0.00	0.02^{***}	-0.01^{*}	-0.05^{***}	-0.10^{***}
	(0.003)	(0.004)	(0.006)	(0.006)	(0.007)	(0.012)
Dealer & Seasonal Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.66	0.66	0.66	0.66	0.66	0.67
Obs	245,363	245,363	245,363	245,363	245,363	245,363

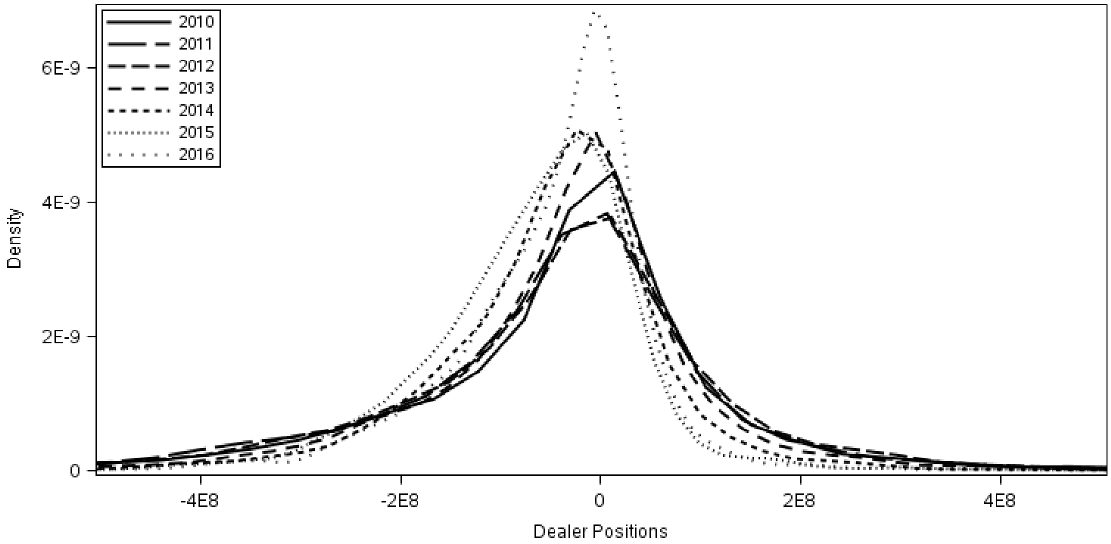
Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation, Markit Group Ltd., and the Financial Industry Regulatory Authority.

The results are similar to the case of aggregate interdealer trading. Individual dealers are less likely to trade with other dealers over time, and the decline is more pronounced in the later years in our sample. We note that, unlike the aggregate results in Table VI, the results at the individual dealer level suggest that, once single name CDS contracts become eligible for clearing, interdealer trading declines by 3-4%.

C. Net dealer inventories in single-name CDS contracts decrease

Figure 6 shows the distribution of dealer inventories for every month and every reference entity for each year in our data. For each reference entity and each month, the inventory of a dealer is measured as the notional position of that dealer, after netting across all of the dealer's positions with all clients and all other dealers in that reference entity for that month. The figure suggests that dealer inventories tighten over time, and are especially tight in 2016.

Figure 6: Dealer Net Notional Inventories



Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

We determine whether there is evidence to support or reject this hypothesis by regressing average, net, dealer inventories on determinants of inventories and indicator variables based on different separating dates.

$$\begin{aligned}\log(Avg.|\text{Dealer Inventory}_{i,j,t}|) =& \beta_0 + \beta_1 \log(\text{Avg. Dealer-Client Volume}_{i,j,t}) \\ &+ \beta_2 \log(\text{Avg. Dealer-Dealer Volume}_{i,j,t}) \\ &+ \beta_3 \log(\text{Avg. Index Volume}_{i,t}) \\ &+ \beta_4 \log(\text{Avg. Bond Volume}_{j,t}) \\ &+ \beta_5 i^j_{\text{Clearing}} + \beta_6 i_{\text{sep}} \\ &+ \text{Dealer fixed effects} + \text{Reference Entity fixed effects} + \varepsilon, \\ &\text{sep} \in \{12/31/2010, 12/31/2011, \ldots, 12/31/2015\}.\end{aligned} \tag{11}$$

The time subscript, t, takes only two values: before the separating date, and after. $Avg.|\text{Dealer Inventory}_{i,j,t}|$ is the net position of dealer i, on reference entity j, either before or after the separating date, averaged at weekly intervals. Avg. Dealer-Client $\text{Volume}_{i,j,t}$ is the volume between dealer i and all its clients on reference entity j; Avg. Dealer-Dealer $\text{Volume}_{i,j,t}$ is the volume between dealer i and all other dealers on reference entity j; Avg. Index $\text{Volume}_{i,t}$ is the volume of index contracts traded by dealer i; Avg. Bond $\text{Volume}_{j,t}$ is the volume of bonds issued by reference entity j. These variables are also averaged at weekly intervals, both before and after the separating date. i^j_{Clearing} is an indicator variable that, for each reference entity, is equal to zero before that reference entity is eligible to be centrally cleared, and one afterwards. i_{sep} is an indicator variable that is equal to 1 after the separating date and 0 otherwise. All variables, other than the indicator variable for the separating date, capture determinants of dealer inventories, while the coefficient of the indicator variable captures the percentage change in dealer net positions before and after the separating date.

Table VIII shows the results for the regression model in Equation (11). The coefficients confirm that, after accounting for potential factors that may influence the level of dealer inventory, net notional inventory held by dealers has declined over time, with the decline slowing down in the latest year in the sample.[19]

Table VIII: Impact on Dealer Inventories

sep	2010	2011	2012	2013	2014	2015
log(Avg. D-D Volume$_{i,j,t}$)	0.09^{***}	0.09^{***}	0.09^{***}	0.10^{***}	0.09^{***}	0.08^{***}
	(0.016)	(0.014)	(0.014)	(0.014)	(0.013)	(0.011)
log(Avg. D-C Volume$_{i,j,t}$)	0.07^{***}	0.06^{***}	0.06^{***}	0.07^{***}	0.08^{***}	0.08^{***}
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
log(Avg. Index Volume$_{i,t}$)	0.02	-0.10^{*}	-0.10^{*}	-0.06	-0.04	0.04
	(0.038)	(0.047)	(0.047)	(0.041)	(0.042)	(0.035)
log(Avg. Bond Volume$_{j,t}$)	-0.05^{**}	-0.03	-0.03	-0.03	-0.06^{**}	-0.03
	(0.018)	(0.02)	(0.02)	(0.021)	(0.022)	(0.023)
i_{Clearing}	0.07^{**}	0.11^{***}	0.11^{***}	0.16^{***}	0.15^{***}	0.14^{**}
	(0.025)	(0.031)	(0.031)	(0.036)	(0.045)	(0.051)
i_{sep}	-0.07^{***}	-0.26^{***}	-0.26^{***}	-0.23^{***}	-0.22^{***}	-0.10^{*}
	(0.019)	(0.041)	(0.041)	(0.037)	(0.041)	(0.04)
Dealer & Reference Entity Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.58	0.57	0.57	0.59	0.57	0.57
Obs	6,156	5,842	5,842	5,659	5,195	4,753

Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation, Markit Group Ltd., and the Financial Industry Regulatory Authority.

D. The volume of client transactions declines

Our model predicts that an increase in the cost of trading results in an overall decrease in the volume of trade for clients. We use a QLR test to explore whether the volume of dealer-to-client transactions, accounting for potential drivers of trade volume, exhibits a structural break.

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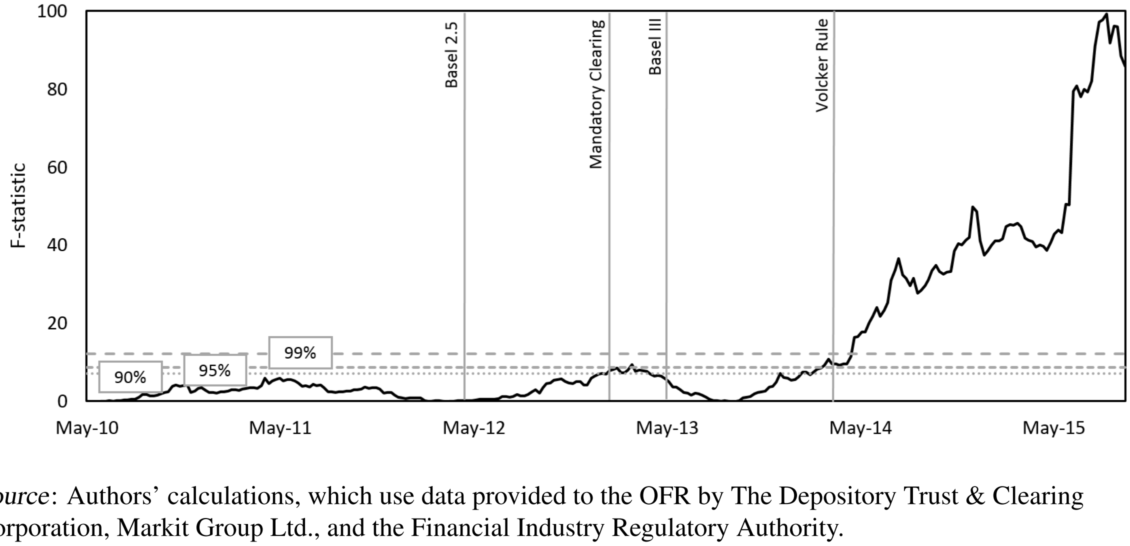
[19] The reason that the number of observations varies with the separating year is that, for a dealer-reference entity to be included we require that a non-zero inventory is held by that dealer in that reference entity both before and after the separating year. Over time, the number of dealers, as well as the number of reference entities they hold inventory in, decline, leading to fewer observations.

The QLR test is based on the following regressions, which account for various factors of demand for CDS contracts

$$
\begin{aligned}
\log(\text{Client volume}_{j,t}) = &\beta_0 + \beta_1 \text{CDS Spread}_{j,t} + \beta_2 \Delta\text{CDS Spread}_{j,t} \\
&+ \beta_3 \text{Recovery Rate}_{j,t} + \beta_4 \log(\text{Dealer-client index volume}_t) \\
&+ \beta_5 \log(\text{Bond volume}_{j,t}) + \beta_6 i^j_{\text{Clearing}} + \beta_7 i_{\text{sep}} + \varepsilon
\end{aligned}
\tag{12}
$$

where Client volume$_{j,t}$ is the aggregate volume of trading in reference entity j at time period t between all dealers and all clients, and dealer-client index volume$_t$ is the aggregate volume of trading in index CDS contracts at time period t, between all dealers and all clients. Similar to Equation (9), the indicator variable, i_{sep}, separates the data into two periods. We shift the time period for the separating date between an early and a late date in the data, and perform one regression for each value across reference entities and dealers. For each regression we calculate the F-statistic for the model with the separating date indicator variable vs. a model without an indicator variable. An increasing value of the F-statistic, as the period corresponding to changes in the separating date, indicates a structural break in the client volume.

Figure 7: QLR Test on Client-Dealer Trading Volume



Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation, Markit Group Ltd., and the Financial Industry Regulatory Authority.

Figure 7 shows the results of the QLR test for Equation (12). The vertical axis shows the F-statistic between a model with the indicator variable separating the two periods and a model without, where standard errors are clustered by time. The test shows that there is a structural break in the client volume. The onset is close to the beginning of the summer of 2014.

Table IX: Client Trading Volume

sep	2010	2011	2012	2013	2014	2015
CDS Spread (5 Y)	1.36^{***}	1.36^{***}	1.35^{***}	1.36^{***}	1.40^{***}	1.42^{***}
	(0.144)	(0.144)	(0.143)	(0.144)	(0.147)	(0.150)
Δ CDS Spread (5 Y)	−0.33	−0.34	−0.33	−0.33	−0.35	−0.36
	(0.193)	(0.194)	(0.192)	(0.193)	(0.199)	(0.202)
Recovery Rate	0.76^{***}	0.77^{***}	0.77^{***}	0.76^{***}	0.75^{***}	0.70^{***}
	(0.109)	(0.110)	(0.110)	(0.110)	(0.111)	(0.111)
log(D-C Index Volume)	0.27^{***}	0.26^{***}	0.24^{***}	0.23^{***}	0.21^{***}	0.20^{***}
	(0.022)	(0.021)	(0.024)	(0.024)	(0.022)	(0.022)
log(Bond Volume)	0.10^{***}	0.10^{***}	0.10^{***}	0.10^{***}	0.10^{***}	0.11^{***}
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
i_{Clearing}	0.06^{***}	0.06^{***}	0.06^{***}	0.06^{***}	0.08^{***}	0.07^{***}
	(0.012)	(0.012)	(0.013)	(0.013)	(0.013)	(0.012)
i_{sep}	−0.04	-0.05^{**}	-0.04^{*}	-0.05^{**}	-0.11^{***}	-0.19^{***}
	(0.027)	(0.017)	(0.018)	(0.020)	(0.023)	(0.036)
Seasonal Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.06	0.06	0.06	0.06	0.07	0.07
Obs	45,826	45,826	45,826	45,826	45,826	45,826

Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation, Markit Group Ltd., and the Financial Industry Regulatory Authority.

Table IX presents the coefficients of the regression as the separating date varies annually. We note that variables that suggest an increase in the riskiness of the bonds of an issuer; i.e., the CDS spread, and the recovery rate, increase the volume of dealer-client transactions.[20] Increased volume of dealer-client transactions in index CDS contracts, and increased volume in the underlying bonds, also increase dealer-client volume in single-name CDS contracts. In addition, the introduction of central clearing for an individual name, even though clearing is

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[20] The recovery rate is a quantity reported by Markit. Markit connects the recovery rate to the implied probability of default. Keeping everything else equal, an increase in the recovery rate suggests that the implied probability of default must increase. Otherwise, an increased recovery rate with a constant implied probability of default would lead to a lower CDS spread.

voluntary, increases client volume by 6-8%. This increase is potentially due to the endogeneity associated with the introduction of central clearing: the single names that are likely to be available to clear are the ones with the largest volumes. Controlling for these factors, the table shows that, over time, client volume declines, with the decline increasing over time.[21]

Table X repeats the regression analysis in Equation (12) by client type. The table presents only the values of the indicator variables for each type of client, and each value of the separating date. The results in the table indicate that, over time, volume declines for all types of clients. The decline is very steep for depository institutions – indicating that the cost of trading is potentially largest for these clients, or that these clients are the most sensitive to an increase in the cost of trading. It is smallest for clients of type Other.

Table X: Trading Volume by Client Type

	2010	2011	2012	2013	2014	2015
Depository Institutions	-0.09^{***}	-0.15^{***}	-0.14^{***}	-0.25^{***}	-0.45^{***}	-0.54^{***}
	(0.015)	(0.020)	(0.023)	(0.025)	(0.023)	(0.023)
Investment Company	-0.02^{***}	-0.07^{***}	-0.09^{***}	-0.16^{***}	-0.18^{***}	-0.20^{***}
	(0.006)	(0.006)	(0.007)	(0.008)	(0.007)	(0.008)
Insurance & Pension	-0.16^{***}	-0.20^{***}	-0.26^{***}	-0.34^{***}	-0.18^{***}	-0.14^{***}
	(0.023)	(0.022)	(0.023)	(0.025)	(0.021)	(0.021)
Other	-0.04	-0.21^{***}	-0.09	-0.16	-0.20^{***}	-0.06^{**}
	(0.049)	(0.041)	(0.051)	(0.056)	(0.053)	(0.056)

Source: Authors' calculations, which use data provided to the OFR by the Depository Trust & Clearing Corporation, Markit Group Ltd., and the Financial Industry Regulatory Authority.

V. Conclusions

We have shown how an increase in the cost of market-making, both in terms of the cost of holding inventory, and in terms of the cost of transacting with other dealers, affects market liquidity, i.e., volume and bid-ask spreads. We have studied the CDS single-name markets during the 2010-16 period, during the implementation of several regulatory reforms, and found

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[21] We provide a robustness test, using only the top 20 percent of most actively traded reference entities in the Appendix.

that the markets have changed. The changes include a shift away from interdealer trading, both on an aggregate level and for individual dealers, a decrease in the net inventories of dealers, a shift towards bid-ask spreads that depend more on inventories of individual dealers rather than on aggregate dealer inventory, and a decline in client volume. Our results are consistent with the regulatory reforms causing an increase in the cost of holding inventories and in the cost of interdealer trading.

While our results indicate that increased costs in the CDS markets have impacted liquidity provision, we cannot rule out that this was the intent of the reforms. To determine the socially optimal level of trading activity it would be necessary to quantify both the benefits and costs of the level of trading. This remains an open question, both theoretically and empirically, for future research.

Our study has focused on the market for single-name CDS contracts. Another market that would be interesting to study in the future is the market for index CDS contracts. This market may be subject to the same costs as the market for single-name CDS contracts, but may also benefit from some of the reforms, for example central clearing requirements, reduced collateral for centrally cleared transactions, and the potential for increased netting for centrally cleared transactions. Whether the benefits outweigh the costs is an empirical question.

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Appendix

A. Comparing Transaction Pricing Data

The transactions that include pricing information are a relatively small percentage of all transactions in the dataset. Table XI presents summary statistics for both sets: transactions with pricing information and transactions without pricing information. We note that priced transactions are more likely to have longer maturities, and to involve clients, but that the notional amounts are similar.

Table XI: Transaction Pricing Data: Robustness Check

Year	2010	2011	2012	2013	2014	2015	2016
	Transactions with Pricing Information						
Average Maturity(Days)	1,559.3	1,471.7	1,423.4	1,387.3	1,553.5	1,453.7	1,529.8
Average Notional($M)	7.0	6.7	7.1	5.6	6.0	5.7	4.7
% of Transactions: Interdealer	67.4	68.8	54.0	51.2	48.6	48.5	33.3
% of Transactions: Dealer-Client	32.8	31.2	46.0	48.8	51.4	51.5	66.7
	Transactions without Pricing Information						
Average Maturity(Days)	1,406.7	1,338.7	1,200.2	1,259.2	1,275.5	1,311.2	1,299.4
Average Notional($M)	6.9	6.3	6.9	6.3	6.8	5.3	5.0
% of Transactions: Interdealer	80.3	85.5	67.5	64.7	62.4	55.0	46.2
% of Transactions: Dealer-Client	19.7	14.5	32.5	35.3	37.6	45.0	53.8

Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation, Markit Group Ltd, and Financial Industry Regulatory Authority.

B. Client volume for liquid contracts

A potential concern regarding our analysis is that our results may be driven by the reference entities with relatively little volume. For example, one possible interpretation would be that, over time, trading in CDS contracts written on the reference entities that are more liquid and have larger volumes remained stable, but that volume dropped significantly on CDS contracts written on reference entities that have lower volumes and are less liquid. To verify that our results on the reduction of the volume of client trading are robust, we repeat our analysis in Equation (12), using only the top 20 percent of reference entities, ranked by the volume of CDS contracts. Our results are presented in Table XII.

Table XII: Client Trading Volume of Top 20% of Contracts by Notional Volume Traded.

sep	2010	2011	2012	2013	2014	2015
CDS Spread (5 Y)	0.76^{***}	0.76^{***}	0.76^{***}	0.77^{***}	0.78^{***}	0.78^{***}
	(0.109)	(0.109)	(0.108)	(0.109)	(0.111)	(0.111)
Δ CDS Spread (5 Y)	-0.12	-0.12	-0.11	-0.12	-0.12	-0.13
	(0.162)	(0.162)	(0.159)	(0.159)	(0.162)	(0.17)
Recovery Rate	0.62^{***}	0.63^{***}	0.64^{***}	0.63^{***}	0.60^{***}	0.53^{***}
	(0.139)	(0.139)	(0.139)	(0.14)	(0.14)	(0.14)
log(D-C Index Volume)	0.33^{***}	0.32^{***}	0.29^{***}	0.28^{***}	0.27^{***}	0.27^{***}
	(0.026)	(0.025)	(0.025)	(0.026)	(0.025)	(0.026)
log(Bond Volume)	0.11^{***}	0.11^{***}	0.11^{***}	0.12^{***}	0.12^{***}	0.12^{***}
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
i_{Clearing}	-0.14^{***}	-0.14^{***}	-0.13^{***}	-0.13^{***}	-0.12^{***}	-0.13^{***}
	(0.013)	(0.014)	(0.014)	(0.014)	(0.014)	(0.013)
i_{sep}	-0.03	-0.04^{*}	-0.05^{**}	-0.06^{**}	-0.11^{***}	-0.14^{***}
	(0.023)	(0.018)	(0.019)	(0.022)	(0.024)	(0.04)
Seasonal Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.11	0.11	0.11	0.11	0.11	0.11
Obs	18,225	18,225	18,225	18,225	18,225	18,225

Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation, Markit Group Ltd, and Financial Industry Regulatory Authority.

Comparing the results in Table XII with the results in Table IX, we note that the same variables are significant and that the coefficients are similar in direction and magnitude, other than the coefficients for the i^j_{Clearing} indicator variables. These coefficients are positive in Table IX, but negative in Table XII. This difference suggests that, overall, clearing is a proxy for liquidity, while, when testing the model only on liquid single names, the introduction of the possibility to clear, results in a reduction in client volume.