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Intermediation Networks and Derivative Market Liquidity: Evidence from CDS Markets

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Mark Paddrik
Office of Financial Research
Mark.Paddrik@ofr.treasury.gov

Stathis Tompaidis
Office of Financial Research
Efstathios.Tompaidis@ofr.treasury.gov

Why These Findings Are Important

The paper highlights the need for policymakers to consider how regulations lead to changes in counterparty relationships. Researchers can use the authors' network measures to study the potential consequences of new regulations or the failure of an intermediary. The authors' measures and methods could provide empirical insight into both the evolution of intermediation and the impact on liquidity. Whether the benefits of these mandates outweigh the costs remains an open question.

Key Findings

1. A dealer's willingness to provide liquidity is positively associated with how well connected a dealer is to its clients and other dealers.
2. Dealer execution costs are primarily driven by a dealer's transactions with clients, while dealers' bid-ask spreads are primarily driven by the dealer's ability to intermediate trade with other dealers.
3. A dealer's execution costs decline as the proportion of relationships the dealer maintains with clients increases, but this cost is not related to the dealer's relationships with other dealers.
4. Bid-ask spreads dealers receive with their clients decline as the completeness of their interdealer network increases.

How the Authors Reached These Findings

The authors introduce a model that links over-the-counter (OTC) derivative markets, intermediary relationships, and derivative market liquidity provision.

The model's predictions highlight that intermediation network density significantly influences the liquidity provided by dealers—both on an individual and a collective basis—as seen through trade volumes, inventory management, and transaction costs.

To evaluate these predictions, the authors empirically examine the U.S. single-name credit default swap (CDS) market, using supervisory data on interdealer and dealer-to-client segments. The authors are the first to empirically assess the differential impacts of the density of these two OTC market segments on the costs of trade.

Intermediation Networks and Derivative Market Liquidity: Evidence from CDS Markets[†]

Mark Paddrik[a]
Stathis Tompaidis[b, *]

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Abstract

In over-the-counter markets, dealers facilitate trade by providing liquidity and acting as intermediaries. We present a model that links the relationships of these intermediaries to market liquidity, and we empirically test the model using supervisory data from the U.S. single-name credit default swap market. We find that the density of the intermediation network has a significant influence on the liquidity provided by dealers, on both the individual and collective level, as seen through trade volumes and inventory management. Further, we find that network density impacts the cost of trade, as measured by execution costs and bid-ask spreads, differentially in the dealer-to-client and interdealer segments.

Keywords: credit default swaps, dealers, intermediation costs, liquidity, OTC trading networks
JEL Classification Numbers: D40, G12, G28, L14

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[a]Office of Financial Research, U.S. Department of the Treasury, 714 14th Street NW, Washington, DC 20005; phone: 202-368-6055; email: Mark.Paddrik@ofr.treasury.gov.

[b, *]McCombs School of Business, University of Texas at Austin, Information, Risk and Operations Management and Finance Departments, 2110 Speedway, Austin, TX 78705; phone: 512-471-5252; fax: 512-471-0587; email: Stathis.Tompaidis@mccombs.utexas.edu. Corresponding Author. Part of this work was completed when the author was at the OFR.

Over-the-counter (OTC) derivatives markets rely on dealers to intermediate risk and provide liquidity through both holding and managing exposures. Dealers build positions with their clients, which impacts the liquidity and the prices they can offer (Duffie et al. (2005); Siriwardane (2019)). To maintain these services, dealers form intermediation networks among themselves and their clients to offset positions (Di Maggio et al. (2017); Hollifield et al. (2017); Li and Schürhoff (2019)). Changes to the intermediation network result in changes to risk exposure management (Hugonnier et al. (2020)) and intermediation costs.[1] The effects of these relationships on the ability of the intermediation network to redistribute positions and offer market liquidity are particularly pronounced in OTC derivative markets since frictions, such as funding and search costs, are smaller in these markets (Eisfeldt et al. (2023)).

In this paper, we examine how intermediation networks and dealer exposures impact the liquidity of one of the OTC derivative markets specifically the market for single-name credit default swaps (CDS).[2] We introduce a model that links OTC intermediary relationships with derivative market liquidity provision. The model's predictions highlight that intermediation network density significantly influences the liquidity provided by dealers, on both an individual and collective basis, as seen through trade volumes, inventory management, and transaction costs. To evaluate these predictions, we empirically examine the U.S. single-name CDS market using supervisory data on two market segments: interdealer and dealer-to-client. Beyond examination of the validity of the model's predictions, we are the first to empirically assess the differential impacts of the densities of these two OTC market segments, on the costs of trade. We find that each segment's intermediation density impacts the cost of trade in the other segment, and influences how dealers offset risk and source liquidity.

In the model, we separate transactions across the interdealer and dealer-to-client networks. We assume that a dealer is a monopolist toward their clients where dealer-to-client transactions are driven by the demand of clients and influenced by bid and ask spreads set by the dealers. Interdealer transactions are made to rebalance risk and reduce inventory costs which are influenced by not

[1] An example studied in the literature is the exit of Drexel Burnham Lambert from the junk bond market in 1990. Brewer and Jackson (2000) show that the exit influenced both the volume of trade and the price of assets. Other examples include the impact of financial innovations on risk-sharing (e.g., the introduction of reinsurance that allowed insurance companies to more easily share risks) and the securitization of mortgages that allowed broader sharing of real estate risk. In both cases, the volume of trading increased.

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

only a dealer's trading relationships but also by the relationships of the dealer's counterparties. In interdealer trading, dealers share the surplus generated from client trades, based on their location in the intermediation network as measured by each dealer's Shapley value. The *Shapley value* is a concept from cooperative game theory, that distributes the surplus generated by trading to rebalance inventories among members of a coalition, based on the marginal contribution of all the counterparties involved in the rebalancing – we make the assumption that dealers engage in a cooperative game because they interact repeatedly. In addition, we assume that as dealers rebalance inventory among themselves to redistribute risks and improve liquidity, they face a deadweight intermediation cost that increases with the length of the intermediation chain. We attribute this cost to increasing coordination and fixed risk management costs for longer intermediation chains.

The model suggests that the interdealer network plays a substantive role in the level of inventories dealers hold and the prices they charge. The model predicts that networks with more dense connections produce greater transaction volume, and, controlling for dealer connections, accommodate higher gross inventory and tighter bid-ask spreads. On the individual dealer level, dealers that are well-connected to other dealers hold larger inventories and offer tighter bid-ask spreads.

We assess the model predictions by using a rich supervisory transaction and position dataset from the U.S. single-name CDS market between 2010 and 2016. This period is particularly interesting due to many changes in the regulation of CDS markets.[3] With these data, we reconstruct the intermediation network of market participants across hundreds of assets. We characterize the density of intermediation networks by constructing measures that capture the trade relationship sets of the dealer-to-client and interdealer segments at the level of a dealer and the level of the market segment. Specifically, we consider the *completeness* of these networks. We define a complete network as one in which every participant is connected to every other participant, and we measure the completeness of an observed network by calculating the ratio of the number of relationships in that network to the number of relationships in the corresponding complete network.

Over the sample period, we find a series of significant changes to intermediation networks: dealer

[3]Following the 2007-09 financial crisis, the Basel II.5 and Basel III accords were implemented, and the United States Congress passed the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 (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.

participation and network density decline, and dealers change the way they manage inventories. These changes provide ample variation to investigate the question of how intermediation networks influence liquidity provision. Using a measure of network density we study three expressions of market liquidity: (i) transaction volume, (ii) the inventory held by individual dealers and the aggregate dealer community, and (iii) the cost of trade through execution costs and bid-ask spreads.

Our paper's first contribution is to show that, in line with the prediction of the model, transaction volumes have a significant and positive relationship with the density of a market's network, for both interdealer and dealer-to-client network segments. A 10 percent increase in the completeness of the interdealer market network is associated with a 6 percent increase in dealer-to-client volume. The effect is larger for the dealer-to-client market network, where a 10 percent increase of completeness is associated with a 27 percent increase in dealer-to-client volume.

Beyond market volume, we also consider how network completeness relates to a measure of risk-bearing capacity for dealers – specifically, the size of inventories – both individually and in aggregate. The literature, as well as our model, suggest that the difficulty of offsetting inventory affects the demand for holding inventory on a dealer's balance sheet and the entry or exit of dealers (Carapella and Monnet (2020)). They predict a positive relationship between both the completeness of dealer and market networks, and the size of a dealer's inventory. Counterparty relationships provide dealers with mechanisms to manage inventory risk, and more complete networks allow for larger inventories to be liquidated quickly, if necessary (Wang (2018); Yang and Zeng (2019)). We test these predictions empirically and confirm that increased completeness of either, or both, the interdealer and the dealer-to-client networks at the individual dealer level is associated with higher dealer inventory levels.

Our second contribution to the literature is our examination of whether the positive relationship between a dealer's network and its inventory holds when controlling for the broader market's network density. We are able to assess the impact of this relationship because, unlike with much of the literature, we can reconstruct both a dealer's network and that of the entire market. We find that, unconditionally, higher levels of completeness at the market level are associated with higher inventory levels. However, when we account for the completeness of individual dealer networks, we find the opposite: higher levels of completeness at the market level are associated with lower individual dealer inventory levels. These results highlight that dealers with more connections are capable of supporting relatively more risk, which is reflected in their higher inventories, due to their advantage in reallocating risk. On the other hand, more complete markets allow more efficient allocation of inventory to clients, reducing dealer inventories broadly.

Beyond dealer and market inventory, the completeness of intermediation networks relates to the cost of transacting in a market. The literature predicts that the cost of transacting is inversely related to the degree of completeness of the network of an individual dealer (Babus and Kondor (2018)). Our model provides a similar prediction, based on changes to a dealer's share of surplus generated by trading. We verify that, similar to previous studies of the ABS, CDO, CMBS, and Non-Agency CMO markets (Hollifield et al. (2017)), and corporate bond market (Di Maggio et al. (2017)), this prediction also holds in the single-name CDS markets.

Our third contribution is to demonstrate how the two market segments of intermediation differentially impact the cost of transactions both within each segment, and among different segments. We find that dealer execution costs are primarily driven by a dealer's transactions with clients. The bid-ask spread between a dealer and its clients declines as the completeness of the dealer's interdealer network increases, while the dealer's interdealer bid-ask spread is not related to its interdealer network. These results are consistent with dealer execution costs being driven largely by a dealer's transactions with clients – and any imbalances they may create in dealer inventories – while the bid-ask spreads are primarily driven by the ability of the dealer to offload inventory with other dealers, but not necessarily with other clients.

At the level of the intermediation network for the entire market, our empirical results are at odds with the theoretical literature (e.g., Babus and Kondor (2018)), which states that more complete market networks are associated with lower execution costs and bid-ask spreads. Instead, we find that a dealer's execution cost when trading with other dealers increases as the completeness of the dealer-to-client network at the market level increases. A possible explanation of the empirical result is that, as the dealer-to-client network becomes more complete, a dealer's need to manage inventory using the interdealer network declines and dealers charge higher execution costs to one another.

Literature Review

The literature on financial market intermediation and the link to a market's liquidity goes back to work by Garman (1976), Stoll (1978), Amihud and Mendelson (1980), and Ho and Stoll (1983).

These early papers propose theoretical models that illustrate how monopolistic dealers manage inventory. Reiss and Werner (1998) and Hansch et al. (1998) use data from the London Stock Exchange – a centralized exchange – and find empirical support for their theoretical predictions. In the case of markets with competing dealers, Ho and Stoll (1983) show that if clients can costlessly transact with multiple dealers, then dealers respond by adjusting their bid-ask spreads to attract client trades that reduce the dealers' inventories. In these models, all volume is concentrated between dealers and clients, and dealers avoid trading with other dealers. To explain the large interdealer volume it becomes necessary to introduce frictions. Wang (2018) and Yang and Zeng (2019) introduce networks where trade is only possible among connected parties and describe how core-periphery networks arise endogenously in OTC markets. Colliard et al. (2021) consider a model of decentralized trading, in which dealers provide liquidity and manage inventory risks and are separated into core and peripheral dealers, based on the efficiency of their trading technology and their connections to other dealers.

Our model's contribution to the existing literature is to offer separate predictions on dealer-to-client and interdealer intermediation networks. The model predicts that networks with more dense connections produce in greater transaction volume, accommodate higher gross inventory, and exhibit tighter bid-ask spreads. We empirically validate several predictions in the literature regarding the relationship between market structure and dealer behavior in an OTC market. We also find that the market-wide network among market participants relates to the liquidity provision of dealers, both individually and collectively, as seen through trade volumes and inventory management. We also document the relationship among execution costs, bid-ask spreads and intermediation. We find that this relationship's effects on interconnectedness and execution costs or bid-ask spreads differ for trades between dealers and clients and trades between dealers.

The CDS market, which is the OTC market setting of our study, has a rich literature examining its function and pricing. Relative to what the empirical network literature says about corporate debt markets, the literature says the CDS market exhibits lower search frictions and synthetic access to otherwise unavailable assets (Oehmke and Zawadowski (2015)). Clients in the CDS markets may trade to hedge risk, to speculate, or to strategically cross-market arbitrage differences in liquidity or price (Oehmke and Zawadowski (2017)). As a result, the liquidity provision of a CDS dealer requires controlling for several factors. Shachar (2012) finds that as with traditional market makers in equity markets, the ability of a CDS dealer to control their clients' order imbalances is central to the dealer's willingness to intermediate and the prices they offer. However, the risk associated with the sudden jump-to-default, poses additional dealer inventory considerations. Siriwardane (2019) finds liquidity spillover effects in CDS bid-ask spreads after the 2011 Japanese earthquake and tsunami. Additionally, the longer-term obligations of CDS contracts require dealers to control for counterparty risk, where a party to a CDS transaction might default at the same time as the underlying reference entity also defaults. Du et al. (2019) 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.

Similar to trade in other OTC markets, CDS trade is segmented into dealer-to-client trades that are, typically driven by clients, and interdealer trades that are primarily used to intermediate risk. Collin-Dufresne et al. (2020) study this segmentation, and find that, for index CDS contracts traded on swap exchange facilities, the price impact is different depending on which segment a transaction takes place in. Specifically, they find that dealer-to-client transactions have a higher average price impact, and that dealer-to-client transactions Granger-cause interdealer transactions, consistent with the interdealer market being used to manage inventory risk. In a related paper, Riggs et al. (2020) focus on the consequences of the centralization of the dealer-to-client trade of index CDS and how clients search for liquidity. They find that dealer-to-collateral relationships are important empirical determinants of customers' choice of trading mechanism and dealers' liquidity provision.

Though the network structure of the CDS markets helps diversify much of the risk, D'Errico et al. (2018) illustrate that the intermediation between hedge funds, that sell risk, and asset managers that purchase risk, results in a large portion of the risk ending up with a few leading risk buyers. Eisfeldt et al. (2023) use a theoretical model to assess the implications of this network transmission channel for how dealers structure their intermediation of CDS counterparty risk. They use the model to study the impact of the potential exit of a key intermediary. In contrast, our paper focuses on the relationship among counterparty networks, reference entity risk intermediation, and measures of market liquidity.

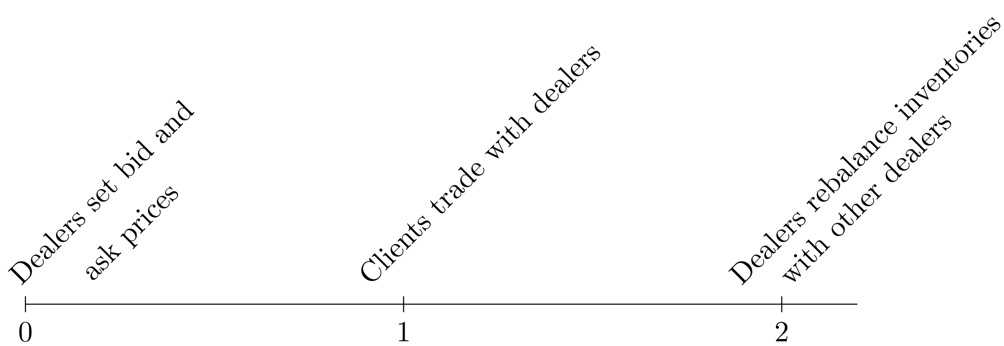
The remainder of this paper is organized as follows. Section 1 introduces a model of dealer intermediation that accounts for the costs of inventory and relationships. Section 2 describes a set of measures that describe the density of intermediation networks. Section 3 derives several propositions connecting intermediation network density and market liquidity. Section 4 provides an overview of the single-name CDS market, describes the data used in our study, and summarize how CDS intermediation has evolved over the period studied. Section 5 presents out empirical tests of the propositions, plus our findings. Section 6 concludes.

1 Model

We consider a model that is in line with empirical observations of OTC derivatives markets. The market is described by a core-periphery network with dealers at the center and clients in the periphery (Peltonen et al. (2014)). Dealers intermediate client transactions with the expectation that they can reduce the underlying risk of the position they assume by offsetting the risk through interdealer trade or contraposition clients.[4] We assume that each client trades with a single dealer, while dealers can trade with multiple clients and multiple dealers.

Figure 1 presents the model timeline. First, dealers start with an initial inventory level and set bid and ask prices. Then, clients trade, based on their demand curve and the posted bid and ask prices. Once a trade occurs, dealers trade in the interdealer market to rebalance their inventories. For simplicity, we assume that the fundamental value of the traded asset is zero with certainty.

Figure 1: Model Timeline



Note: The model timeline includes three periods. In period 0, dealers hold inventories and set bid and ask prices. In period 1, clients trade based on their demand curve and the posted bid and ask prices. Once a trade between a dealer and a client occurs, in period 2 dealers trade in the interdealer market to rebalance their inventories.
Source: Authors' creation.

[4]We note that, unlike traditional debt securities which can be difficult to borrow, derivative contracts are relatively easy to short.

1.1 Dealers

Dealers are assumed to face convex inventory costs, which can be attributed to regulatory costs associated with a dealer's balance sheet usage, a dealer's risk aversion when the value of the traded asset is uncertain, or the higher financing costs associated with larger inventories (O'Hara (1998)). Unique to a derivatives market setting and unlike in the underlying securities markets, dealer does not need to maintain inventory to be able to provision buy-side liquidity. Thus, dealers have an incentive to trade with each other, as well as with clients, to reduce these costs. We assume that each dealer can only trade with dealers they maintain a master agreement with (i.e. is connected to), and that the interdealer network is known and fixed. Furthermore, we assume that the interdealer network is connected (i.e., there exists at least one path linking each dealer to every other dealer). We assume that all dealers face identical convex inventory costs and that their preferred inventory exposure (i.e., the position that minimizes their costs) is zero.[5]

Beyond inventory costs, we assume that dealers face a *deadweight cost* – in which the cost increases with the length of the intermediation chain that is needed to rebalance dealer inventory – when they transact with other dealers. This assumption reflects higher clearing costs and settlement costs (e.g., due to increased exposure to counterparty risk) and operational inefficiencies that increase when more dealers are involved (e.g., for example due to a greater difficulty to coordinate). To keep the problem tractable, we assume that intermediation cost is a percentage of the surplus generated by rebalancing inventory (i.e., that intermediation cost does not deter inventory rebalancing).

Assuming that dealers' initial inventories after trading with customers are $\{i_v\}_{v=1}^{n}$, the inventory level that minimizes inventory costs across the entire network of dealers is the same for each dealer. Since the interdealer network is connected, this level of inventory can be reached through interdealer trading. This inventory level is given by:

$$i_f = \frac{1}{n}\sum_{v=1}^{n} i_v \tag{1}$$

[5]The assumption that the preferred position of every dealer is zero is made without loss of generality. The problem in which dealers have nonzero, and potentially different, preferred positions is equivalent to the problem with zero preferred positions after a change of variables that shifts the entire market inventory by the net preferred position of all the dealers.

1.2 Dividing Surplus in Interdealer Trading

Given an inventory cost function, $c_{\text{inv}}(\cdot)$, which is assumed to be convex and with a minimum value equal to zero for zero inventory, $c_{\text{inv}}(0) = c'_{\text{inv}}(0) = 0, c''_{\text{inv}}(\cdot) > 0$, the surplus associated with reduced inventory generated by interdealer trading is given by the aggregate inventory cost before interdealer trades minus the aggregate inventory cost after interdealer trades. Interdealer transactions also involve a cost that depends on the average length of the intermediation chain[6], r, that is needed to rebalance dealer inventory, $c_{\text{int}}(\cdot)$. We assume that the intermediation cost increases with the length of the intermediation chain, $c'_{\text{int}}(\cdot) > 0$, and that the intermediation cost is only a percentage of the surplus generated by rebalancing inventory, $c_{\text{int}}(\cdot) < 1$:

$$\text{Trade Surplus} = (1 - c_{\text{int}}(r)) \left(\sum_{v=1}^{n} c_{\text{inv}}(i_v) - n c_{\text{inv}}(i_f) \right) \geq 0, \tag{2}$$

where the non-negativity of the surplus follows by the convexity of the inventory cost function.

To divide any surplus associated with trading between dealers we calculate dealer Shapley values, a concept from cooperative game theory to distribute gains across actors working in coalition (Shapley (1951)). In our setting, a dealer's Shapley value reflects the dealer's value as a member of a coalition that redistributes inventory – the Shapley values depend on each dealer's inventory and position in the network. Shapley values have several desired properties: they are efficient in the sense that all the surplus is divided among all the agents; they are symmetric in the sense that coalition members that contribute equally are compensated equally; and they are calculated based solely on the marginal contributions of each player. The Shapley values is the only payment rule that satisfies these properties (Young (1985)). Our motivation for using Shapley values is that, due to the repeated nature of dealer interaction, dealers engage in a cooperative game to share the surplus generated from trade. Shapley values provide a distribution based on a player's marginal contribution to the total payoff across all possible coalitions and satisfy efficiency as the sum of the payoffs to all players equals the total value of the grand coalition, promoting a motivation for players to contribute to the collective effort. In addition, the predictable method of dividing gains

[6] The average shortest path length is defined as the average number of steps along the shortest paths for all possible pairs of network nodes. To calculate the average shortest path length consider the graph G with the set of vertices V. Let $d(v_1, v_2)$, where $v_1, v_2 \in$V denote the shortest distance between v_1 and v_2. Assume that $d(v_1, v_2) = 0$ if v_2 cannot be reached from v_1. Then, the average shortest path length is equal to $\frac{1}{n \cdot (n-1)} \cdot \sum_{i \neq j} d(v_i, v_j)$, where n is the number of vertices in G.

provided by Shapley values can foster trust and reduce the likelihood of conflicts, issues that are important in relationships over the long term in repeated games.[7]

To calculate the Shapley value for a specific dealer that is a member of a coalition associated with a trade, we consider all coalitions that do not include the dealer, and then we determine the added value of including the dealer in the coalition. The Shapley value is the average marginal contribution of the dealer when they are added to all possible coalitions. The surplus of all coalitions of size 1 is zero since, in this case, no rebalancing is possible. For coalitions of size 2, consider all combinations of dealers p, q, where $p, q = 1, \dots, n, p \neq q$. If the dealers are not connected, then the surplus is zero. Otherwise, the surplus is given by:

$$(1 - c_{\text{int}}(1)) \left(c_{\text{inv}}(i_p) + c_{\text{inv}}(i_q) - 2c_{\text{inv}}(\frac{i_p + i_q}{2}) \right) \geq 0 \tag{3}$$

where $c_{\text{inv}}(i_p) + c_{\text{inv}}(i_q)$ is the aggregate inventory cost for dealers p, q, prior to trading, while $2c_{\text{inv}}(\frac{i_p+i_q}{2})$ is the aggregate inventory cost after trading. The surplus reflected in the difference in inventory costs is adjusted by $(1 - c_{\text{int}}(1))$ to account for the intermediation cost associated with an intermediation chain of length equal to one.

In general, for a specific coalition of $d \leq n$ dealers, we decompose the set of the d dealers into all possible subsets of connected dealers. By construction, each dealer belongs to exactly one such subset, and the decomposition is unique and based on the overall set of relationship connections. The surplus is given by

$$(1 - c_{\text{int}}(r)) \left(\sum_{v=1}^{d} c_{\text{inv}}(i_v) - \sum_{\{S\}} |S| c_{\text{inv}}(\frac{\sum_{p \in S} i_p}{|S|}) \right) \geq 0 \tag{4}$$

where $\{S\}$ is the set of connected subsets of d dealers, $|S|$ is the cardinality of the set of members of the connected subset S, and $p \in S$ are the dealers that belong to subset S.[8]

A dealer's Shapley value is the average marginal contribution of adding the dealer to any coalition that does not include them. If the dealer is connected to any of the members of the coalition, their marginal contribution will be non-negative – and strictly positive if their inventory is different

[7]We note that alternative value concepts for cooperative games exist. In particular, in a model where players may exit the game, long term stability may not be needed, and an alternative axiomatization of dividing surplus may be preferable.

[8]We allow for subsets of size 1, to include cases of dealers that are not connected to any of the other $k-1$ dealers.

from the inventory of the pre-existing members. Otherwise, their marginal contribution will be zero. This implies that the Shapley value of each dealer is non-negative. Similarly, we conclude that holding all else equal, adding a new trading relationship agreement between two dealers either increases the Shapley value for both dealers or, at worst, leaves the Shapley value unchanged. The increase occurs when the additional agreement creates situations in which previously disconnected subsets of dealers become connected, generating additional surplus by distributing inventory more efficiently.

We note that, given our assumption that the interdealer network is connected, adding connections between dealers does not increase the surplus generated by distributing inventory across the entire interdealer network. However, additional connections do reduce the intermediation cost as the average length of the intermediation r decreases.

1.3 Clients

Clients have private valuations that differ from zero and are captured by a downward-sloping curve for long positions and another downward-sloping curve for short positions. The demand curves are modeled as a function of the probability that a client would transact with a dealer: the dealer sets a bid (ask) price, and each client sells (buys) one unit of the asset with a probability that depends on the difference between the bid (ask) price and zero.[9] We assume that as the bid (ask) price approaches either zero or minus (plus) infinity, the profit of the dealer (i.e., the product of the bid (ask) price and the expected number of transactions) goes to zero.

Each dealer v is connected to n_v^c clients that can only transact with them. For simplicity, we assume that a dealer's clients are equally likely to be either buyers or sellers, but not both, and that clients do not transact simultaneously. Given the bid price, b_v, and the ask price, a_v the expected demand, if the clients are buyers (sellers), is determined by a demand function that declines as prices increase (decrease), reflected by the probability $d_b(a_v)$ for buying from dealer v (the probability $d_a(b_v)$ for selling from dealer v). As soon as a transaction between one dealer and one of her clients occurs, the dealer rebalances her portfolio with the other dealers and then all dealers set new bid and ask prices.

[9] We do not restrict the bid price to be below zero or the ask price to be above zero. Dealers may sell an asset at a price below its fundamental value or buy it at a price above its fundamental value, realizing a loss, to avoid other costs associated with holding inventory.

Each dealer sets the optimal bid and ask prices with clients to maximize their profits. Since the value of a claim is equal to zero, the expected revenue from selling a unit (buying a unit) is equal to the ask (minus bid) price times the probability of a sales (purchase): $a_v d_b(a_v)$ $(-b_v d_a(a_v))$. The marginal cost of the transaction to the dealer is given by the cost of transacting with other dealers to offset the transaction and rebalance their portfolio, as well as the impact of the trade on the overall inventory. The following proposition describes how the bid and ask prices change if the dealer's overall marginal cost of rebalancing changes.

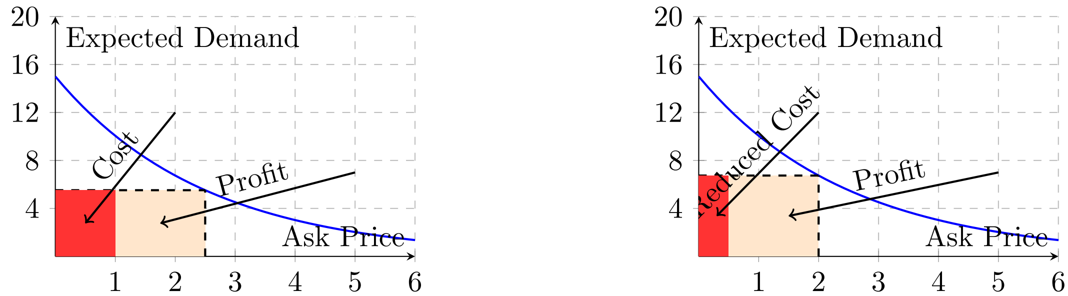
Proposition 1 *Assume that the dealer's profit function is twice differentiable with respect to the ask (bid) price, and that there exists a unique ask (bid) price* $a^*(b^*)$*, that optimizes the dealer's profit. Then, if the dealer's overall marginal cost to rebalance their portfolio decreases by a small enough amount, there exists a new optimal ask (bid) price,* $a^{**}(b^{**})$*, that is lower (higher) than the original optimal ask (bid) price. Similarly, an increase of the dealer's overall cost to rebalance their portfolio results in a higher (lower) ask (bid) price.*

We provide a proof of the proposition in Appendix B. We note two applications of this proposition: (1) when a dealer acquires a new connection and (2) when the interdealer network becomes denser. To understand what occurs in these two cases we recall that the marginal cost for a dealer transacting with a client consists of the dealer's increased inventory cost minus the benefit that the dealer derives from transacting with the remaining dealers to rebalance her portfolio; i.e., minus the dealer's Shapley value that measures the share of the trade surplus captured by the dealer transacting with the client.

In the case where a dealer acquires a new connection her Shapley value increases. This means that she captures a bigger share of surplus generated by trade, resulting in a lower marginal cost, and, from Proposition 1, a tighter bid-ask spread. In the second case, due to the denser network, the average length of the intermediation chain decreases, again leading to a lower marginal cost and a tighter bid-ask spread.

Figure 2 illustrates the intuition behind the proposition for the case in which the overall cost is described by the function $(1 - c_{\text{int}}(r))d_b(a_v)\,(\tilde{c}(v+1) - \tilde{c}(v))$; where $\tilde{c}(\cdot)$ corresponds to the inventory cost faced by the dealer after rebalancing their inventory in the interdealer market. Figure 2a illustrates the base case, while Figure 2b illustrates the case in which the marginal cost is lower, resulting in a lower ask price.

Figure 2: Optimizing Ask Price



(a) Original Cost　　**(b)** Reduced Marginal Cost

Note: Panels (a) and (b) show how the optimal ask price changes as the marginal cost is reduced – the optimal ask price in panel (b) is lower than the optimal ask price in panel (a).
Source: Authors' creation.

2 Intermediation Network Measurement

To capture the impact of network topology on quantities such as trading volume, bid-ask spreads, and execution costs, we would, ideally, use direct measures of the Shapley value of each dealer, that is, the division of the surplus among the set of dealers, $\mathcal{D}$, as well as the cost due to the length of the intermediation chain, both for individual dealers, and for the entire market. Since this is difficult to do in a general network, and since the density of the network of interdealer relationships influences the Shapley values, we instead propose measures of *completeness*, which are measures that capture dealer connectivity, and that directly affect the length of the intermediation chain.

The first measure of completeness is at the level of individual dealers and corresponds to the percentage of other dealers each dealer is connected to. Since the interdealer network is connected, the measure of dealer-to-dealer completeness can vary between $1/(n-1)$ and 1, where n is the total number of dealers, $1/(n-1)$ corresponds to a dealer connected to only one other dealer, and 1 corresponds to a dealer connected to all other dealers.[10]

[10]Beyond completeness, there are two measures commonly used in the network literature at the level of individual dealers: network centrality and network closeness. Network centrality is a measure that captures a dealer's relative position in the network in terms of how many other dealers they are connected to. Network closeness measures the average length of the shortest intermediation chain between a dealer and all other dealers. Our measure of network completeness for individual dealers is similar to both of these measures.

Given the matrix that describes the trade relationships between all market participants, $\mathbf{W}$, where w_{ij} is equal to 1 if a trade relationship exists between counterparties i and j, we measure the completeness of a dealer's intermediation network, $\mathrm{k}_i^{\mathrm{D}}$, relative to the set of all dealers, $\mathcal{D}$, defined as:

$$\textbf{Interdealer Dealer Completeness}: \mathrm{k}_i^{\mathrm{D}} = \frac{\sum_{j \neq i} w_{ij}}{|\mathcal{D}| - 1}, \quad i,j \in \mathcal{D}; \tag{5}$$

The second measure considers the completeness of the entire interdealer network. The market level interdealer network completeness is measured by counting the number of counterparty relationships relative to the complete set of dealer pairs possible. Assuming that dealers are in the set $\mathcal{D}$, the number of counterparty relationships in a complete market is $|\mathcal{D}|(|\mathcal{D}| - 1)/2$. Thus interdealer market completeness is defined as:

$$\textbf{Interdealer Market Completeness}: \ \mathrm{K}^{\mathrm{D}} = \frac{\sum_i \sum_{j>i} w_{ij}}{|\mathcal{D}|(|\mathcal{D}| - 1)/2}, \quad i, j \in \mathcal{D}; \tag{6}$$

The measure of interdealer market completeness provides a comprehensive understanding of the full set of relationships in a market. For example one can compare the interdealer dealer completeness of an individual dealer to the interdealer market completeness measure as a proxy for the relative completeness of the dealer's counterparties' relationships.

Beyond the two measures that capture the intermediation network between dealers, we introduce two additional measures that capture the intermediation network between dealers and clients. Similar to the measure of interdealer dealer completeness, we introduce a measure at the level of individual dealers, client dealer completeness, which computes the percentage of clients a dealer is connected to.[11] Client dealer completeness is defined as:

$$\textbf{Client Dealer Completeness}: \mathrm{k}_i^{\mathrm{C}} = \frac{\sum_{j \neq i} w_{ij}}{|\mathcal{C}|}, \quad i \in \mathcal{D}, j \in \mathcal{C}. \tag{7}$$

Similar to the case of the measure of interdealer market completeness, we also construct a market level measure that computes the completeness of the network between dealers and clients

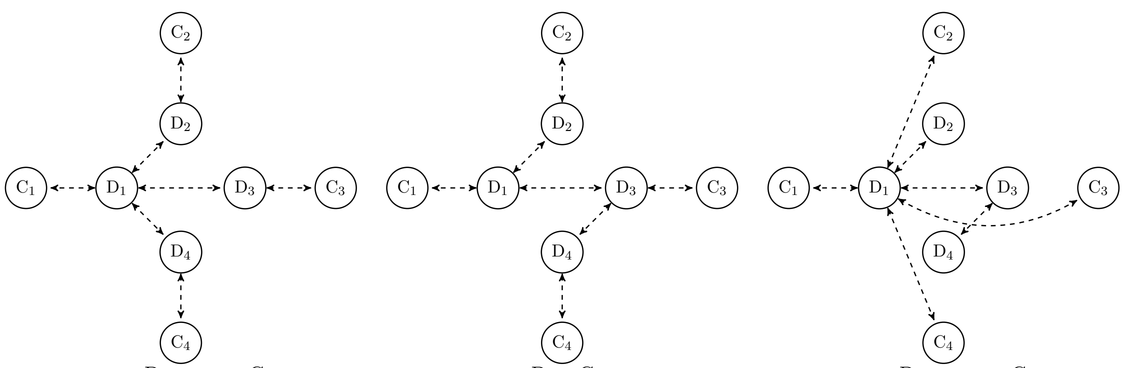
[11] While our model does not directly consider the effect of a dealer having more clients than another dealer, access to more clients can have benefits. For example, in cases where transactions between dealers are costly, perhaps due to regulatory constraints, access to additional clients may allow a dealer to rebalance her portfolio by finding a counterbalancing transaction with another client, rather than through interdealer trading.

by counting the number of counterparty relationships relative to all the possible relationships. Given a set of dealers, $\mathcal{D}$, and clients, $\mathcal{C}$, the number of all possible relationships between dealers and clients is $|\mathcal{D}||\mathcal{C}|$. Thus, client market completeness is defined as:

$$\textbf{Client Market Completeness}: \ \mathrm{K}^{\mathrm{C}} = \frac{\sum_i \sum_j w_{ij}}{|\mathcal{D}||\mathcal{C}|}, \quad i \in \mathcal{D}, j \in \mathcal{C}. \tag{8}$$

Figures 3 and 4 present examples of intermediation networks and compare them based on the values of the two network measures. In Figure 3 the number of relationships among dealers and those among clients and dealers is the same for each network, but the networks are different. Consider Figure 3b as our reference point, with an intermediation network where no dealer is connected to all other dealers or all clients. For this network, the client dealer completeness and the interdealer dealer completeness are equal to 25 percent and 67 percent respectively for dealer D_1. In this network, dealers D_1 and D_3 have a privileged position with respect to dealers D_2 and D_4 due to their higher interdealer connectivity which lets them capture a bigger share of the total surplus from interdealer transactions.

Figure 3: Intermediation Network and Dealer Liquidity



(a) High $\mathrm{k}_1^{\mathrm{D}}$, Low $\mathrm{k}_1^{\mathrm{C}}$ for D_1 Network

(b) Low $\mathrm{k}_1^{\mathrm{D}}$, $\mathrm{k}_1^{\mathrm{C}}$ for D_1 Network

(c) Low $\mathrm{k}_1^{\mathrm{D}}$, High $\mathrm{k}_1^{\mathrm{C}}$ for D_1 Network

Note: Figures (a) through (c) present example trading networks where dealers, D_i, and clients, C_j, are depicted as nodes, and dashed links represent established trade relationships. The variations across the networks highlight differences in $\mathrm{k}_1^{\mathrm{D}}$, $\mathrm{k}_1^{\mathrm{C}}$ for dealer D_1 while keeping K^{D} and K^{C} the same. Network (b) is the base case and represents a sparse trading network where D_1 has one out of four client relationships in the dealer-to-client market and two out of three dealer relationships in the interdealer market. Network (a) represents a complete interdealer trading network for D_1, such that all dealer intermediation flows through D_1. Network (c) represents a complete dealer-to-client trading network for D_1, where all client intermediation flows through D_1.
Source: Authors' creation.

Figure 3a is an intermediation network where the client relationships remain the same as Figure 3b but the interdealer relationships are different. Dealer D_1 is connected to every other dealer while other dealers are only connected to dealer D_1. In this case, for dealer D_1, the client dealer completeness and the interdealer completeness are equal to 25 percent and 100 percent, respectively. This is an example of a network where dealer D_1 has more options to rebalance their inventory relative to other dealers and captures a higher share of the trade surplus.

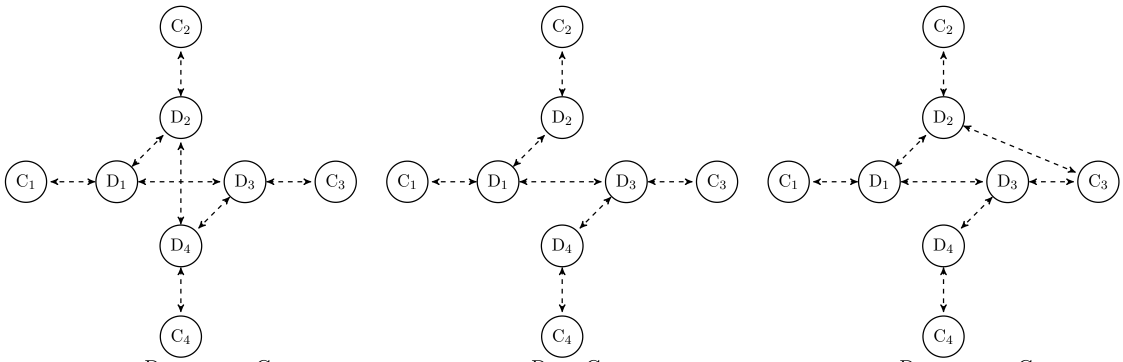
Figure 3c is an intermediation network where the dealer relationships are the same as in Figure 3b, but the client relationships are different. In this case only dealer D_1 is connected to clients, while other dealers are not. For dealer D_1, the completeness of the client dealer network is 100 percent, while the completeness of their interdealer network is 67 percent. In this intermediation network dealer D_1 captures the same share of trade surplus as other dealers – but because the dealer has relationships with more clients, the dealer has more flexibility to manage their inventory by directly trading with clients.

Figure 4 illustrates market network measures. Unlike the previous examples, the number of relationships between dealers and the number of relationships between clients and dealers is not constant. However, in this figure, the network completeness measures for dealer D_1 are held constant. As our reference point, consider Figure 4b: an intermediation network where no dealer is connected to all other dealers or all clients. In this case, the client market completeness and the interdealer market completeness are equal to 25 percent and 50 percent, respectively. In this network dealers D_1 and D_3 have a privileged position with respect to other dealers since each of them has relationships with two other dealers, but no dealer has a complete interdealer or client network.

Figure 4a is an intermediation network where dealer D_1's interdealer relationships remain the same as in Figure 4b but a new interdealer relationship exists between dealers D_2 and D_4. The result is that no dealer has a privileged position with respect to other dealers (i.e., they earn an equal share of the surplus). The client market completeness and the interdealer market completeness are equal to 25 percent and 66 percent, respectively. In contrast, Figure 4c is an intermediation network where dealer D_1's client relationships remain the same as in Figure 4b but a new client relationship exists between client C_3 and dealer D_2. In this case, the completeness of the client market network and the interdealer market network are equal to 33 percent and 50 percent, respectively.

Note that examples suggest that additional relationships in the market networks or the networks of individual dealers, may have an impact on intermediation and the share of surplus that individual

Figure 4: Intermediation Network and Market Liquidity



(a) High K^{D}, Low K^{C} for D_1 Network

(b) Low K^{D}, K^{C} for D_1 Network

(c) Low K^{D}, High K^{C} for D_1 Network

Note: Figures (a) through(c) present example trading networks where dealers, D_i, and clients, C_j, are depicted as nodes, and dashed links represent established trade relationships. The variations across the networks highlight differences in K^{D} and K^{C} while keeping k_1^{D} and k_1^{C} the same for dealer D_1. Network (b) is the base case and represents a sparse market network. Network (a) represents an increase in the completeness of the interdealer market network relative to (b). Network (c) represents an increase in the completeness of the dealer-to-client market network relative to (b).
Source: Authors' creation.

dealers realize; these relationships may , also potentially result in a measurable difference in the liquidity of trades between dealers and clients, between dealers, or both.

3 Intermediation Networks and Liquidity

In this section, we provide a series of propositions about the influence of intermediation network relationships on market liquidity, based on the model in Section 1. These additional propositions are straightforward corollaries of Proposition 1, and discuss the relative influence that a dealer and the collective intermediation chains created by the interdealer segment have on three measures of liquidity: transaction volume, dealer inventory, and trading costs.

3.1 Intermediation Network & Transaction Volume

Oehmke and Zawadowski (2017) find that transaction volume reflects the demand for both hedging and speculation within derivative markets. In the context of the model, a denser network reduces the length of the intermediation chain and the corresponding intermediation cost. These reduced costs translate into tighter bid-ask spreads that, due to downward sloping demand, lead to increased transaction volume. Thus:

Proposition 2 *The completeness of a market's intermediation network is positively related to the transaction volume between dealers and clients.*

Proof. From the model, a more complete intermediation network reduces the average length of the intermediation chain and the deadweight costs associated with the interdealer network. From Proposition 1, this lower cost corresponds to tighter bid-ask spreads, and, due to the declining client demand curve, an increase in the transaction volume between dealers and clients. ■

The intuition behind this proposition is that intermediation network completeness allows for more efficient trading as it increases the dealers' opportunities to find a counterparty with whom they can trade. The proposition is consistent with prior findings in Babus and Kondor (2018) that suggest that increased completeness of the network of a dealer should lead to an increase in the dealer's propensity to learn more through trade such that the dealer may lower its costs, and earn a higher expected profit. Generalizing this finding further, one expects that a better-informed market, measured through the completeness of the market's trading network, is associated with higher trading volumes.[12]

3.2 Intermediation Network & Dealer Inventories

In contrast with the corporate debt market(Hollifield et al. (2017); Di Maggio et al. (2017); Li and Schürhoff (2019)), dealers in derivative markets are not supply constrained (i.e., they do not need to hold inventory to supply liquidity to clients wishing to purchase). Thus, transaction volumes reflect the willingness of dealers to supply liquidity to their clients. However, this willingness depends on the ability of dealers to manage market risk and balance sheet space.

Proposition 3 *The completeness of a dealer's intermediation network is positively related to the dealer's risk-bearing capacity (i.e. the dealer's net inventory).*

Proof. In the model, dealers with more interdealer relationships capture a bigger share of the surplus generated by trading with other dealers. This means that their intermediation costs are lower and that they are thus able to offer tighter bid-ask spreads. This means that they are more

[12]While the proposition only addresses the transaction volume between dealers and clients, we note that Gofman (2017) has shown that increased market completeness may decrease overall interdealer trade volume as fewer intermediation trades are necessary.

likely to have their bids and asks accepted, resulting in them having, on average, bigger inventories relative to other dealers. ■

Proposition 3 is in line with much of the theoretical literature. Neklyudov (2019) finds that dealers with better search technology (i.e., dealers that are better connected) find trade opportunities more easily, and thus have relatively high trade execution efficiency. This increased efficiency lowers the risk level of well-connected dealers' inventories and allows such dealers to take on higher inventory levels (Gofman (2017)).

Proposition 4 *The completeness of a market's intermediation network, controlling for the completeness of the intermediation network of individual dealers, is:*

a. positively related to the risk-bearing capacity of individual dealers (i.e., their net inventory); and

b. positively related to the gross risk-bearing capacity of all dealers (i.e., the sum of the absolute value of dealer inventories.)

Proof. Increasing market completeness, while controlling for individual dealer completeness reduces the deadweight intermediation cost, without influencing the relative share of the trade surplus each dealer receives. This means that, individually, as well as in aggregate, dealers face lower transaction costs and can offer tighter bid-ask spreads and manage bigger inventories. ■

Proposition 4 is similar to other papers in the literature. Neklyudov (2019) suggests a similar outcome though the result depends on inventory risk. Gofman (2011) finds that under the bilateral bargaining frictions of OTC markets, efficient inventory allocation can occur only when the trading network is complete. Yang and Zeng (2019) argue that dealers hold higher inventories if other dealers do so due to strategic coordination motives. When the inventory management costs are sufficiently low (high), a dealer is more (less) willing to provide liquidity – e.g,, by buying an asset from a seller, holding a high level of inventory, and then selling the asset to a buyer later. This implies a higher (lower) aggregate dealer inventory and a larger (smaller) dispersion of the distribution of dealer inventory.

3.3 Intermediation Network & Transaction Costs

In the context of our model, a dealer with a more complete network receives a larger share of the surplus generated by trading. It is effectively able to transact at lower execution costs and is consequently able to offer better bid-ask spreads to its counterparties.

Proposition 5 *The completeness of a dealer's intermediation network is negatively related to the execution cost and the individual dealer bid-ask spread.*

Proof. Similar to the proof of the other propositions, a dealer with a more complete interdealer intermediation network is able to capture a bigger share of trade surplus (i.e., enjoy a lower execution cost). The higher surplus translates into lower intermediation costs, and, from Proposition 1, the dealer can offer tighter bid-ask spreads. ■

Proposition 5 focuses on the completeness of the network of an individual dealer and is similar to propositions on dealer centrality found in the literature. Babus and Kondor (2018) predict that this feature is due to clients being less concerned about adverse selection from dealers and from well-connected dealers being able to learn prices better than other dealers. These predictions are consistent with the empirical findings in Hollifield et al. (2017) and Di Maggio et al. (2017) for the case of the corporate bond market. However, both of these empirical papers are limited in that they only observe interdealer networks when assessing trading costs. As a result, it is unclear how important each part of a dealer's network is in influencing the cost of a trade.

Proposition 6 *The completeness of a market's intermediation network, conditional on the completeness of the intermediation network of individual dealers, is negatively related to the execution cost and bid-ask spreads faced by individual dealers.*

Proof. Conditional on the completeness of the intermediation network of individual dealers, an increase in the completeness of the market intermediation network reduces the deadweight cost of interdealer trade, resulting in lower execution costs and tighter bid-ask spreads. ■

Comparing Proposition 6 to the literature, Babus and Kondor (2018) find that, under a theoretical OTC market setting, a determinant of a dealer's trading cost, besides their centrality, is the centrality of their counterparties. This theoretical result is supported empirically. Hollifield et al. (2017) and Di Maggio et al. (2017) find that the centrality of both dealer counterparties matters for assessing the cost of a trade. In contrast, Hendershott et al. (2020) examine dealer-to-client networks and the impact a client's relationship has on the prices they receive. However, since these papers are limited to the observation of only one market segment, it is not clear whether the results hold after controlling for interdealer and dealer-to-client networks.

4 Credit Default Swap Market

A single-name credit default swap (CDS) insures against losses on a bond of a corporate issuer, following the issuer's default. If the corporate issuer of the bond does not default before the maturity of the contract, the CDS contract expires worthless.[13] In the case of default, the seller of CDS protection pays the purchaser the difference between the bond's face value and default auction value. Single-name CDS contracts are traded through an over-the-counter market with a core-periphery microstructure of trade. A small number of dealers intermediate trade among themselves and with a larger number of clients on the periphery (Siriwardane (2019)). Dealers intermediate credit risk by buying and selling CDS contracts, either as a service to clients or to hedge internal corporate bond holdings and risks. On the other hand, clients including depository institutions, insurance companies, and investment companies, such as hedge funds and investment funds, trade CDS contracts to hedge exposure to the default of a corporation, to speculate on potential default, or to synthetically create corporate bond positions.

4.1 Data

Our data include every CDS transaction on which the reference entity is a U.S.-domiciled corporation, as well as the weekly positions of every participant in this market between 2010 and 2016. Having access to every transaction and weekly position of every participant allows us to construct trade relationship networks between market participants, including those between dealers and between dealers and clients.

The CDS transaction and position data are provided by The Depository Trust & Clearing Corporation (DTCC).[14] DTCC provides trade processing services for most major dealers in CDS

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

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

markets. After a trade is registered with DTCC, it is recorded in 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, where the transactions involve a U.S. counterparty or a U.S. reference entity. The data also include 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 35 percent of transactions include the credit spread at which the transaction took place. The total number of U.S. CDS reference entities with senior-tier debt is 1032, while the total number of dealers is 32.[15] In addition, we collect information on the volume of index CDS contracts that we use as controls in our models.

We enhance the information in the TIW dataset, with data from Markit Group Ltd. that 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 the IDSA default documentation clauses. We use the most liquid maturity of five years, senior reference obligations, U.S. dollar denominated contracts, and average overall 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 TIW and Markit datasets to implicitly determine the date when CDS contracts on a reference entity become eligible for central clearing; we set the date to the first time when we observe a transaction between a dealer and the central counterparty on the reference entity or when the reference entity becomes part of a CDS index.

In cases in which 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, we can determine whether the buyer or the seller initiates the transaction. If the transaction spread is above the Markit spread, we assume that the buyer initiated the transaction. If it is below, we assume that 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.[16] In addition, we determine whether

[15] Dealers are identified in the TIW data by DTCC, as dealers are responsible for submitting transaction data.

[16] In the case in which an up-front 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 is used in Iercosan and Jiron (2017). Similar to

a transaction is dealer initiated or client initiated, based on which side paid the implied bid-ask spread.[17]

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. TRACE allows us to map CDS contracts to the underlying corporate bonds and to calculate the volume of trading for the underlying corporate bond. Unlike the TIW dataset, not all counterparties are identifiable in TRACE, which requires volumes to be aggregated at the market level.

4.2 CDS Market Statistics

The CDS markets developed in the early 1990s and grew substantially in the run-up to the 2007-09 financial crisis. As a result of it and the role CDS played in the crisis, several regulatory reforms were enacted during the time of our study.[18] Table 1 presents summary statistics for the single-name CDS market during this period, with variables averaged monthly and split by year. We note that the average number of dealers per reference entity declined during the period. While the average number of clients and the 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 interdealer trades, which dropped by more than 95 percent. The number of dealers each client trades with remained stable, while, consistent with the decline in the number of dealers, the number of clients per dealer increased. Finally, consistent with the decline in the volume between dealers, the number of interdealer counterparties for each dealer declined.

Table 2 presents information on transaction prices, averaged annually. We note that CDS spreads, measured in basis points, have dropped over time, while bid-ask spreads, measured as a

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our use of the Markit credit spread to calculate the bid-ask spread of a specific transaction, Iercosan and 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.

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

[18] These reforms include the Basel 2.5 and Basel III accords, rules requiring standardized financial contracts be cleared through central counterparties, the Volcker rule, margin requirements for bilateral transactions, and others. Several papers in the literature study the secondary market for corporate bonds and find that, over the same period, liquidity and the behavior of participants changed (see Adrian et al. (2017); Dick-Nielsen and Rossi (2019); Bessembinder et al. (2018); and Bao et al. (2018)). Similarly, we find that liquidity in the U.S. single-name CDS market decreased, and we identify changes in the behavior of dealers that coincide with the implementation of several of these regulatory reforms.

Table 1: Monthly CDS Market Statistics per Single-name Reference Entity

Year:	2010	2011	2012	2013	2014	2015	2016
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)
# 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)

Note: The table presents average monthly summary statistics for the volume, number of trades, and number of dealers and clients per reference entity, by year. Volume is reported in $ millions by CDS reference entity.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

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

4.3 CDS Intermediary Inventories

As dealers intermediate the CDS market, they need to manage and offset the risk of open positions on their balance sheet – these actions in turn influence the degree of liquidity an intermediary can provision. Using the supervisory data, we calculate the net reference entity market risk held by a dealer across all of its outstanding CDS positions. The net notional inventory, $x_{i,j,t}$, of a dealer i on a reference entity j across the set of dealer $\mathcal{D}$, and client, $\mathcal{C}$, counterparties at time t is calculated as

$$\textbf{Dealer Inventory}: \; x_{i,j,t} = \sum_{k} x_{i,k,j,t}, \quad i \in \mathcal{D}; k \in \mathcal{D}, \mathcal{C} \tag{9}$$

Figure 5 plots the annual density distribution of dealer net notional inventories, $x_{i,j,t}$, in our

Table 2: Transaction Price Statistics per Single-name Reference Entity

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

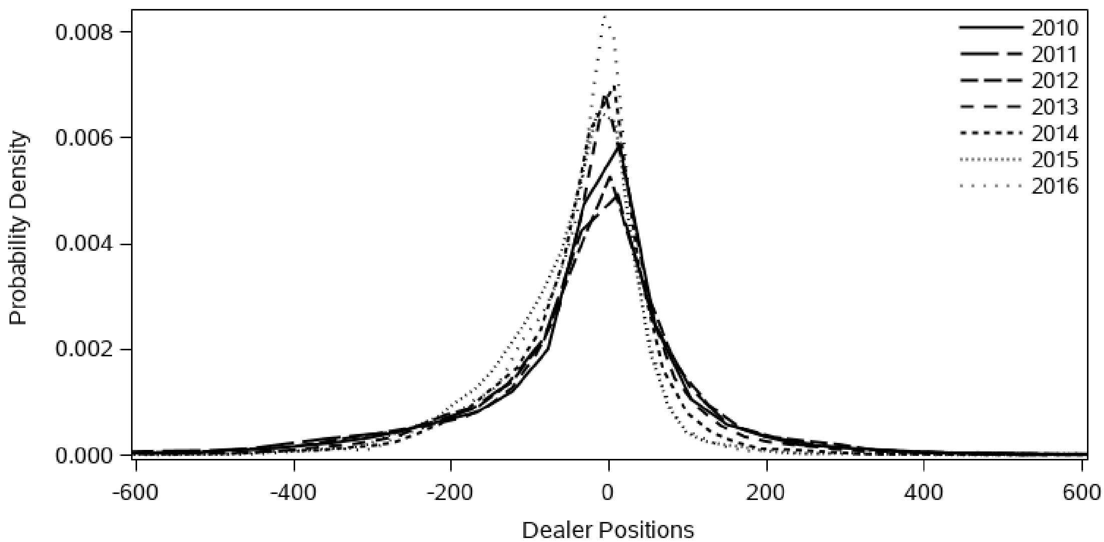
Note: The CDS spread is the annual average Markit CDS spread, measured in basis points across the CDS reference entities. The bid-ask spread is calculated by finding the distance that a transaction occurs at, relative to the daily Markit CDS spread and it is presented as a percentage of the daily Markit CDS spread. The table presents average and standard deviation (in parentheses) information for both interdealer and client-dealer transactions. Client-dealer transactions are separated into client-initiated, and dealer-initiated, transactions based on which side paid the implied bid-ask spread. The last three rows 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.

sample. The distributions demonstrate a relatively symmetric pattern consistent with dealers being risk-neutral in their preferences. However, dealers do show some preference for being more short than long in their holdings, as the mean of each year's distribution is between -\$18 and -\$42 million, and there is some negative skewness. Additionally, consistent with the decline in CDS market volumes, we find declining levels of inventory held, which is suggestive of tightening liquidity conditions.

To assess the total amount of dealer inventory, we create aggregate measures: net dealer inventory, representing the netted reference entity risk that could remain after potential trades in the interdealer segment; and gross dealer inventory, representing the gross reference entity risk held by dealers. These are defined as

$$\textbf{Net Dealer Inventory}: \; X_{j,t} = \sum_i x_{i,j,t}, \quad i \in \mathcal{D}; \tag{10}$$

Figure 5: Dealer Net Notional Inventory



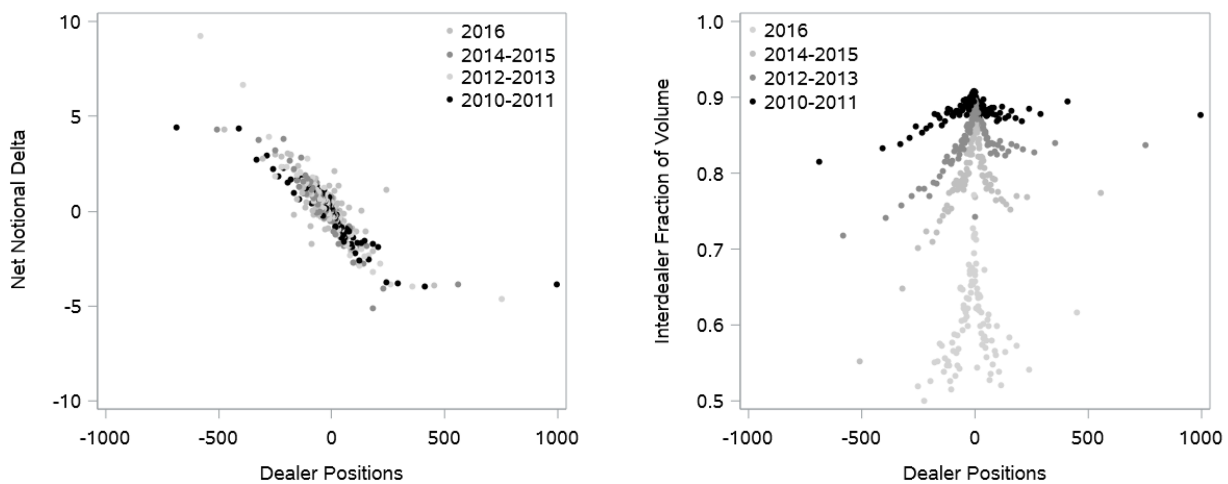
Note: The plot presents the probability density function of weekly dealer notional positions (in \$ millions), by year, across our sample of U.S. single-name CDS reference entity markets. The overlay highlights the tightening of inventory by dealers over time.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

$$\textbf{Gross Dealer Inventory}: \; Y_{j,t} = \sum_i ||x_{i,j,t}||, \quad i \in \mathcal{D}. \tag{11}$$

In examining CDS dealers' inventory management practices, we observe a few patterns across the data. Figure 6(a) plots week-over-week change in dealer positions, $x_{i,j,t+1} - x_{i,j,t}$, against the dealer's position, $x_{i,j,t}$. The sample is grouped into dots corresponding to a centile of the distribution of net positions in each reference entity for a given set of years. In line with results in the microstructure literature for other markets (see Hansch et al. (1998)), the figure shows that dealers tend to decrease the size of their inventories when they deviate from a net zero position for every year in the data .

How dealers achieve reductions in inventories depends on which segment of the market, interdealer or dealer-to-client, is willing to provide liquidity relative to the cost of holding inventory. Figure 6(b) sheds light on how the reduction is achieved, and how it evolves. The plot shows the fraction of dealer i's volumes, $\lambda_{j,t}$, traded along the interdealer segment, $\lambda^{\mathrm{D}}_{j,t}$, grouped by sample years. While interdealer transactions are the most common form of inventory management over all 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, which is consistent with the view that trading between dealers has become increasingly difficult, particularly as a function of the level of a dealer's inventory (Wang and Zhong (2022)). The choice and usage of each segment is likely to be influenced by the intermediation network of the others.

Figure 6: Dealer Inventory Management



(a) Weekly Inventory Change Given Previous Weeks Inventory

(b) Interdealer Fraction of Trade Given Previous Weeks Inventory

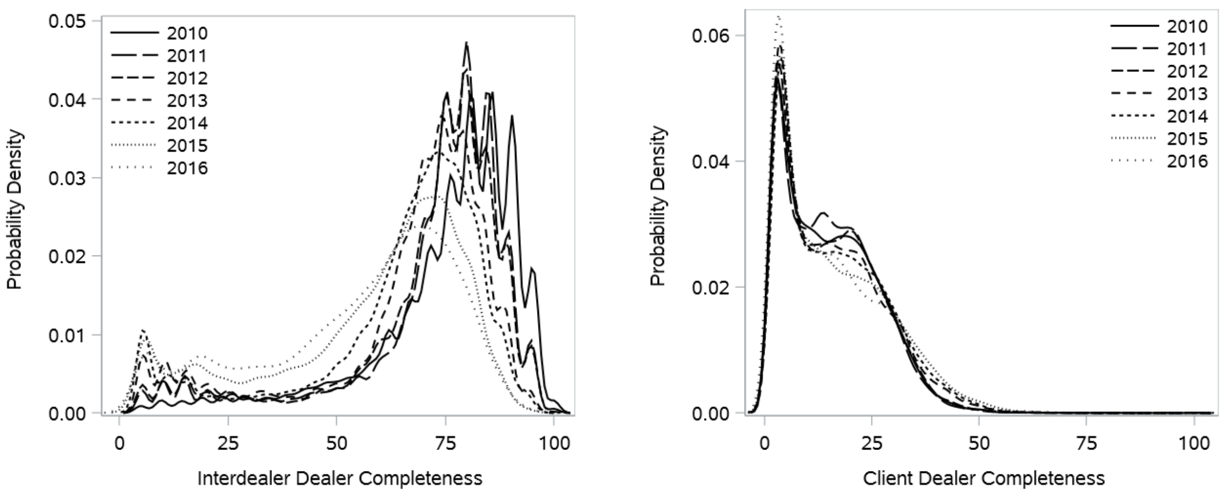
Note: Plots (a) and (b) illustrate inventory management practices in the single-name CDS market. Plot (a) shows week-over-week changes in dealer inventory, relative to the previous week's inventory (in \$ millions). Each point presents the average weekly inventory change grouped by years and centile of the previous week's dealer inventory. The plot highlights that as inventories grow away from zero, dealers work to reduce their inventory risk. Plot (b) shows the fraction of interdealer trade volume relative to the previous week's inventory (in \$ millions). Each point presents the average weekly fraction of interdealer trade, grouped by years and centile of the previous week's dealer inventory. The plot illustrates a tightening of inventory by dealers over time, and a growing tendency of dealers to offset inventories with clients when inventories are further from zero.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

4.4 CDS Intermediation Networks

The intermediation networks of dealers and markets evolved over the period covered by our data. To capture the network of relationships, we estimate the existence of non-public master agreements, which govern whether two firms can transact in a particular security. While the master agreements are not directly observable, the supervisory dataset does provide an imperfect but conservative substitute through the counterparty-level positions. The existence or absence of a position over the sample allows us to define the **W** matrix of relationships between market participants.

We note that, as participation in a market may not be constant, the transaction data only indicate whether dealers and clients are active market participants. As many single-name reference entity contracts transact relatively infrequently, we adjust the set of firms included in the $\mathbf{W}$ matrix using a five-week rolling window to define the set of active dealers, $\mathcal{D}$, and clients, $\mathcal{C}$. To ensure significant variation in trading volume and networks, we limit the sample to reference entities with at least four dealers with non-zero positions during the sample period.

Figure 7: Dealer Network Completeness Distribution



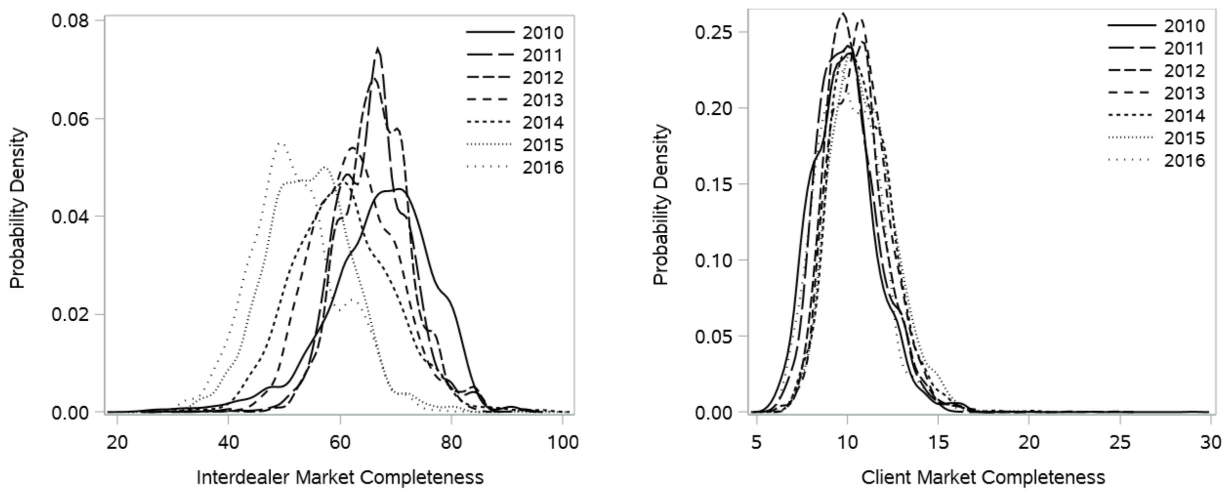
(a) Interdealer Dealer Completeness **(b)** Client Dealer Completeness

Note: Plots (a) and (b) present the probability density function of interdealer and client dealer completeness, by year, across our sample of U.S. single-name CDS reference entity markets. The overlay highlights that interdealer interconnectedness shifts over the sample period, with more recent years showing a decline in interdealer trading relationships at the participant level.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

Figure 7 presents annual density distributions for dealer-level network measures. While the shape of the distribution of both completeness measures is consistent across time, the mean interdealer dealer completeness measure declines. We do not observe the same decline in the dealer-to-client network measures. We note that the distribution of interdealer network measures is bi-modal and left-skewed. This shape suggests that most dealers have relatively complete relationships with other dealers, while a few dealers use the market to offset positions for a single client or hedge their risks. The distribution of the dealer-to-client network measures is right-skewed, suggesting that most dealers intermediate for a few client and occasionally a single client.

Figure 8 presents the annual density distributions for market level network measures. Similar to the dealer level completeness distributions, the market level measures reveal that the completeness of the interdealer network has declined, and the dealer-to-client network has remained steady over the sample period. We find that dealers, on average, are much more well-connected to one another than they are to clients, which is consistent with the core-periphery structure typically observed in OTC markets.

Figure 8: Market Network Completeness Distribution



(a) Interdealer Market Completeness **(b)** Client Market Completeness

Note: Plots (a) and (b) present the probability density function of interdealer and client market completeness, by year, across our sample of U.S. single-name CDS reference entity markets. The overlay highlights that interdealer interconnectedness shifts over the sample period, with more recent years showing a decline in interdealer trading relationships at the market level.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

5 Empirical Findings

In this section, we empirically assess the propositions in Section 3 against their respective measures of liquidity: market volume, dealer inventories, transaction execution cost, and bid-ask spread. In testing the relationship between intermediation networks and derivative market liquidity, we include controls for dealer, market, substitute market, and time fixed effects.[19]

5.1 Dealer-to-Client Transaction Volume

Our first measure of market liquidity is market volume, specifically, client trade volume (λ^{C}). To test Proposition 2, we construct a model for the determinants of client volume (λ_j^{C}) for the

[19]Table A.1 in the Appendix provides a full list the variables we use in our models.

market of single-name CDS contracts for reference entity j. Since client trade volume is measured at the market level, we only include measures of completeness of the interdealer (K^{D}) and the dealer-to-client (K^{C}) market networks, lagged by a period.[20]

When modeling trade volume, it is necessary to account for fundamental drivers of demand for CDS contracts. We account for demand by including variables that capture the riskiness of the underlying name, such as the CDS spread, the change in the CDS spread, and the CDS recovery rate; and variables that capture direct hedging needs, such as the volume of trading in the underlying bond and CDS indices.

The model also accounts for the introduction of central clearing to U.S. CDS markets within our sample period. For each single-name reference entity, we include a clearing indicator, $\mathbb{1}_{j,t}^{\text{Clearable}}$, corresponding to whether and when that reference entity became eligible to clear at a central counterparty. We also include the share of interdealer volume, $\lambda_{j,t}^{\mathrm{D}}/\lambda_{j,t}$,, which captures the degree of difficulty in offsetting trades (Wang (2018)).

The model also includes indicator variables that capture time variation, $\mathbb{1}^{\mathrm{M/Y}}$, and seasonality, $\mathbb{1}^{\mathrm{M}}$, at the market level. Seasonality is natural in trading volume due to the regular schedule of issuing new series of CDS contracts. The model is given by:

$$\begin{aligned}\log(\lambda_{j,t}^{\mathrm{C}}) =& \beta_0 + \beta_1 \mathrm{K}_{j,t-1}^{\mathrm{D}} + \beta_2 \mathrm{K}_{j,t-1}^{\mathrm{C}} + \beta_3 \text{CDS Spread}_{j,t} + \beta_4 \Delta\text{CDS Spread}_{j,t} \\ &+ \beta_5 \text{CDS Recovery Rate}_{j,t} + \beta_6 \log(\text{Bond } \lambda_{j,t}) + \beta_7 \log(\text{Index } \lambda_t^{\mathrm{C}}) \\ &+ \beta_8 \mathbb{1}_{j,t}^{\text{Clearable}} + \beta_{82} \lambda_{j,t}^{\mathrm{D}}/\lambda_{j,t} + \beta_{10-20} \mathbb{1}^{\mathrm{M}} + \beta_{21-82} \mathbb{1}^{\mathrm{M/Y}} + \epsilon. \end{aligned} \tag{12}$$

The period, t, in the regression model in Equation (12) is one week. All variables are calculated each week as many single-name CDS contracts trade infrequently. The results, reported in Table 3, indicate a significant relationship between the risk of a reference entity and the trading volume for the corresponding CDS contract. The CDS spread and its estimated recovery rate are significantly positively correlated with volume.[21] The results are consistent with intuition: as the risk, measured by CDS spreads, increases, we expect hedging demand by holders of existing debt to also increase.

[20] We have explored models without lagging the completeness measures and we have found similar results. They are available upon request.

[21] The recovery rate represents the extent to which principal and accrued interest on defaulted debt can be recovered. Higher credit quality debt has higher recovery rates. Recovery rate is typically also correlated with the size of traded debt outstanding.

Table 3: Intermediation Network and Client Volume

	Dependent Variable			
	log(Client Volume)			
	(1)	(2)	(3)	(4)
Intercept	4.1000***	3.5409***	3.7766***	3.4533***
Interdealer Market Completeness		0.0082***		0.0061***
Client Market Completeness			0.0379***	0.0267***
CDS spread	1.3409***	1.2907***	1.1012***	1.1341***
ΔCDS spread	-0.2721	-0.2476	-0.1929	-0.1978
CDS Recovery Rate	0.7434***	0.5875***	0.6129***	0.5346***
log(Bond Volume)	0.1139***	0.1218***	0.1080***	0.1157***
log(Client Index CDS Volume)	0.2481***	0.2495***	0.2503***	0.2506***
CDS Clearing Eligible	-0.0005	0.0163	0.0395***	0.0402***
Interdealer Volume Share	-0.0096***	-0.0097***	-0.0097***	-0.0097***
Time Fixed Effects	Y	Y	Y	Y
Observations	36,248	36,248	36,248	36,248
Adjusted R^2	27.09%	28.29%	28.18%	28.76%

Note: The table presents the results of Equation (12) for the relationship between measures of network completeness, characteristics of the underlying reference entity, and client volume.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation and FINRA.

We find that the eligibility of a CDS contract to be cleared is positively correlated with increasing volume, in line with Loon and Zhong (2014). This is consistent with the facts that clearing eligibility is largely based on whether a particular CDS contract is part of a CDS index, and that index inclusion is based on whether a CDS contract is heavily traded. The coefficient of the share of interdealer volume is negative, meaning that a higher share of interdealer trade is associated with lower client volumes.

The results involving market network completeness measures indicate that the measures are positively related to increased client volume for both the interdealer and the dealer-to-client market networks. This relationship is not only statistically significant but also economically significant. The regression coefficient indicates that an increase in the completeness of the interdealer market network by 10 percent is associated with an increase of dealer-to-client volume by 6 percent. Increasing the completeness of the dealer-to-client network at the market level has a bigger effect. A 10 percent increase in completeness is associated with a 27 percent increase in dealer-to-client volume. These results are consistent with Proposition 2 and suggest that network completeness is a proxy for lower costs of trading in the network.

5.2 Individual & Aggregate Dealer Inventory

The size of dealer inventories, both individually (x_i) and in aggregate ($\sum_i \|x_i\|$), depends on many factors including the cost that dealers face to hold inventory or trade with other market participants.[22] These same factors influence the network structure for the interdealer and dealer-to-client networks, at both the individual dealer level and the aggregate market level. Proposition 3 states that, for individual dealers, the completeness of their intermediation networks is positively related to their inventory. As far as market completeness is concerned, Proposition 4 states that, controlling for completeness of intermediation networks of individual dealers, market completeness should be positively associated with both a dealer's inventory and the aggregate, gross, inventory of all dealers in the market.

We study these relationships with two models, one for the inventory of individual dealers and another for aggregate dealer inventory, by reference entity j. In addition to the network completeness measures, the explanatory variables include the client volume, $\lambda^{\mathrm{C}}_{j,t}$, the share of interdealer trade, an indicator variable capturing whether and when the CDS contract became eligible for clearing, and variables that capture time variation and reference entity, $\mathbb{1}^{\mathrm{R}}_j$.

$$\begin{aligned}\log(\|x_{i,j,t}\|) =&\beta_0 + \beta_1 \mathrm{K}^{\mathrm{D}}_{j,t-1} + \beta_2 \mathrm{K}^{\mathrm{C}}_{j,t-1} + \beta_3 \mathrm{k}^{\mathrm{D}}_{i,j,t-1} + \beta_4 \mathrm{k}^{\mathrm{C}}_{i,j,t-1} + \beta_5 \mathbb{1}^{\mathrm{Clearable}}_{j,t} \\ &+ \beta_6 \log(\lambda^{\mathrm{C}}_{j,t}) + \beta_7 \lambda^{\mathrm{D}}_{j,t}/\lambda_{j,t} + \beta_{8-89}\mathbb{1}^{\mathrm{M/Y}} + \beta_{90-386}\mathbb{1}^{\mathrm{R}}_j + \epsilon,\end{aligned} \tag{13}$$

$$\begin{aligned}\log(\textstyle\sum_i \|x_{i,j,t}\|) =& \beta_0 + \beta_1 \mathrm{K}^{\mathrm{D}}_{j,t-1} + \beta_2 \mathrm{K}^{\mathrm{C}}_{j,t-1} + \beta_3 \mathbb{1}^{\mathrm{Clearable}}_{j,t} + \beta_4 \log(\lambda^{\mathrm{C}}_{j,t}) \\ &+ \beta_5 \lambda^{\mathrm{D}}_{j,t}/\lambda_{j,t} + \beta_{6-87}\mathbb{1}^{\mathrm{M/Y}} + \beta_{88-384}\mathbb{1}^{\mathrm{R}}_j + \epsilon.\end{aligned} \tag{14}$$

Tables 4 and 5 present the results of Equations (13) and (14). Both sets of results suggest that network completeness is associated with the risk capacity and level of inventories of dealers, both individually and in aggregate. In particular, at the level of individual dealers, Table 4 shows that explanatory power for individual dealer inventory increases significantly when dealer-level network measures are included in the model.

In line with Proposition 3, the coefficients of individual dealer completeness measures are sig-

[22] We model dealer level inventories by the logarithm of the absolute value of individual inventories, while we measure aggregate market inventory by the logarithm of the sum of the absolute values of individual dealer inventories.

nificant and positive, suggesting that well-connected individual dealers hold larger inventories. The effect is significant for both the interdealer network and the client network: a 10 percent increase in the completeness of the interdealer network for an individual dealer is associated with a 13 percent increase in its inventory level, while a 10 percent increase in the completeness of the dealer-to-client network of an individual dealer is associated with an increase in of 5 percent in the inventory level. These results suggest that dealers with more connections to other dealers and clients have greater risk-bearing capacity, due to their ability to more easily reduce their positions in the future (if necessary) through their trading network.

In contrast with Proposition 4, Table 4 shows that, after controlling for measures of completeness of intermediation networks of individual dealers, individual dealer inventory declines as the completeness of the interdealer market increases. A 10 percent increase in the completeness of the interdealer market is associated with a 5 percent decrease in individual dealer inventory. Rather than increasing risk-bearing capacity for the entire network, this result is consistent with a more connected market being able to better spread – and net – inventories across dealers.

At the aggregate market level, the results in Table 5 demonstrate the importance of a market's intermediation network. Consistent with Proposition 4, regarding aggregate market inventory, as the completeness of the market level interdealer and dealer-to-client networks increases, the aggregate gross dealer inventory increases as well. For example, a 10 percent increase in each measure is associated with an increase in the aggregate gross dealers inventory of 4 percent, and 11 percent respectively. This finding suggests that well-connected networks have higher risk-bearing capacity, which in turn supports liquidity under periods of stress due to high client demand.

5.3 Execution Cost & Bid-Ask Spread

The network of trading relationships between dealers and clients has the potential to influence, and reflects, the cost of executing a trade, not just for individual dealers, but for the entire market. Proposition 5 states that the completeness of the intermediation network of an individual dealer is negatively related to that dealer's cost of trade; i.e., the execution cost and bid-ask spreads faced by the dealer. In contrast, Proposition 6 states that the completeness of the market's intermediation network, after controlling for the intermediation network of a dealer, is negatively related to the trading cost faced by the dealer.

Table 4: Intermediation Network and Dealer Inventory

	Dependent Variable			
	log(Dealer ‖Inventory‖)			
	(1)	(2)	(3)	(4)
Intercept	7.5027***	6.4385***	7.3278***	6.7409***
Interdealer Dealer Completeness		0.0124***		0.0129***
Client Dealer Completeness		0.0051***		0.0047***
Interdealer Market Completeness			0.0027***	-0.0052***
Client Market Completeness			0.0006	-0.0014
CDS Clearing Eligible	0.0116***	0.0251***	0.0115***	0.0263***
log(Client Volume)	0.0015	0.0032	0.0009	0.0045**
Interdealer Volume Share	0.0000	0.0000	0.0000	0.0000
Time Fixed Effects	Y	Y	Y	Y
Reference Entity Fixed Effects	Y	Y	Y	Y
Observations	470,264	470,264	470,264	470,264
Adjusted R^2	9.14%	22.13%	9.19%	22.31%

Note: The table presents the results of Equation (13) for the relationship among measures of network completeness, characteristics of the underlying reference entity, and the inventory of individual dealers.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

Table 5: Intermediation Network and Market Inventory

	Dependent Variable			
	log(Σ Individual Dealer ‖Inventory‖)			
	(1)	(2)	(3)	(4)
Intercept	8.5227***	8.2679***	8.3913***	8.2076***
Interdealer Market Completeness		0.0042***		0.0035***
Client Market Completeness			0.0172***	0.0106***
CDS Clearing Eligible	0.0904***	0.0916***	0.0921***	0.0924***
log(Client Volume)	0.0158***	0.0146***	0.0149***	0.0143***
Interdealer Volume Share	0.0002***	0.0002***	0.0002***	0.0002***
Time Fixed Effects	Y	Y	Y	Y
Reference Entity Fixed Effects	Y	Y	Y	Y
Observations	36,508	36,508	36,508	36,508
Adjusted R^2	81.54%	82.05%	81.86%	82.15%

Note: The table presents the results of Equation (14) for the relationship among measures of network completeness, characteristics of the underlying reference entity, and aggregate gross market inventory for CDS contracts on a single-name reference entity.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

We consider two measures of trading cost for a transaction: the execution cost and the bid-ask spread. We define the execution cost, μ, as

$$\mu_{i,j,t} = \frac{\text{CDS Transaction Spread}_{i,j,t} - \text{CDS Spread}_{j,t}}{\text{CDS Spread}_{j,t}}(2 \times \mathbb{1}^{\text{buyer}} - 1). \tag{15}$$

While the bid-ask spread captures the cost of transacting irrespective of who the buyer and who the seller is, the execution cost captures the cost of transacting from the point of view of the entity transacting. For example, if the CDS transaction spread is above the average CDS spread given by Markit, the execution cost is positive for a buyer and negative for a seller.

We construct two models of execution cost from the perspective of a dealer; one model for the case when the dealer trades with a client – execution cost $\mu^C_{i,j}$ – and another for the case when the dealer trades with another dealer – execution cost $\mu^D_{i,j}$. In addition to the network completeness measures, the explanatory variables include the number of dealers with positions in reference entity j, $|\mathcal{D}_j|$, and, in an effort to capture potential inventory costs, several variables involving dealer inventory. These variables are the level of the inventory of individual dealer i for reference entity j, $\log(\|x_{i,j}\|)$, the aggregate net dealer inventory $\log(\|X_j\|)$, the aggregate gross dealer inventory $\log(Y_j)$, as well as the aggregate, gross, inventory separated in long and short positions.[23] The remaining variables control for the dealer share of total volume, time variation, reference entity fixed effects, and whether the CDS contracts on a reference entity are eligible for clearing.

$$\begin{aligned}\mu^{\mathrm{C}}_{i,j,t} =& \beta_0 + \beta_1 \mathrm{K}^{\mathrm{D}}_{j,t-1} + \beta_2 \mathrm{K}^{\mathrm{C}}_{j,t-1} + \beta_3 \mathrm{k}^{\mathrm{D}}_{i,j,t-1} + \beta_4 \mathrm{k}^{\mathrm{C}}_{i,j,t-1} + \beta_5 \log(\|x_{i,j,t}\|) + \beta_6 \log(\|X_{j,t}\|) \\ &+ \beta_7 \log(Y_{j,t}) + \beta_8 \mathbb{1}^{\mathrm{Clearable}}_{j,t} + \beta_9 |\mathcal{D}_{j,t}| + \beta_{10} \lambda^{\mathrm{D}}_{j,t}/\lambda_{j,t} + \beta_{11-92} \mathbb{1}^{\mathrm{M/Y}} + \beta_{93-389} \mathbb{1}^{\mathrm{R}}_j + \epsilon,\end{aligned} \tag{16}$$

$$\begin{aligned}\mu^{\mathrm{D}}_{i,j,t} =& \beta_0 + \beta_1 \mathrm{K}^{\mathrm{D}}_{j,t-1} + \beta_2 \mathrm{K}^{\mathrm{C}}_{j,t-1} + \beta_3 \mathrm{k}^{\mathrm{D}}_{i,j,t-1} + \beta_4 \mathrm{k}^{\mathrm{C}}_{i,j,t-1} + \beta_5 \log(\|x_{i,j,t}\|) + \beta_6 \log(\|\mathrm{X}_{j,t}\|) \\ &+ \beta_7 \log(\textstyle\sum_i \|x_{i,j,t}\|) + \beta_8 \mathbb{1}^{\mathrm{Clearable}}_{j,t} + \beta_9 |\mathcal{D}_{j,t}| + \beta_{10} \lambda^{\mathrm{D}}_{j,t}/\lambda_{j,t} + \beta_{11-92} \mathbb{1}^{\mathrm{M/Y}} + \beta_{93-389} \mathbb{1}^{\mathrm{R}}_j + \epsilon.\end{aligned} \tag{17}$$

Table 6 presents the results for the dealer execution cost for dealer-to-client transactions. We note that the execution cost increases with the size of the inventory of the transacting dealer, suggesting that dealers with large inventories have difficulty offloading risk when trading with clients. We do not find evidence that execution cost in transactions with clients depends on market inventory, either net or gross. We also do not find support for Propositions 5 and 6 regarding the link between completeness measures and dealer execution cost when trading with clients, as the

[23]The separation in long and short positions is meant to capture potential differences in client motivations between buying and selling CDS contracts.

execution cost does not exhibit significant dependence on any network measures.

Table 7 presents the results for the interdealer execution cost. Unlike in the case of transactions between dealers and clients, the execution cost no longer depends on individual dealer inventories. On the other hand, the execution cost depends on whether contracts on a reference entity are eligible to clear: contracts that are eligible to clear are more expensive to trade with other dealers by 13 basis points, indicating that clearing may be costly. We find some support for Proposition 5, as we find that a 10 percent increase in a dealer's client network completeness decreases their interdealer execution cost by 42 basis points.

However, we do not find support for Proposition 6 after controlling for a dealer's client network. Instead of finding an association of lower costs with higher levels of market completeness for the dealer-client market network, we find that as completeness increases, interdealer execution costs increase as well. A potential explanation lies in the interplay between interdealer trading costs and a dealer's need to offset client trades. Similar to the results shown in Table 4 for Proposition 4, it is possible that, as a dealer's dealer-to-client network becomes denser, their has less need to offset positions through the interdealer network and may only do so when the execution costs are low. However, if the dealer-client market completeness increases because all dealers have higher dealer-to-client network completeness, the cost to trade with another dealer increases since the individual dealer's network is no longer as advantageous and the need for interdealer transactions declines, causing execution costs to grow.

Our last measure of the cost of trading a CDS contract is the bid-ask spread. Since we do not observe bid or ask quotes, we follow the literature and estimate the bid-ask spread by measuring the distance between the credit spread of a specific transaction and the average CDS spread given by Markit.[24] We define the bid-ask spread (γ) to be:

$$\gamma_{i,j,t} = \frac{\text{CDS Transaction Spread}_{i,j,t} - \text{CDS Spread}_{j,t}}{\text{CDS Spread}_{j,t}} \quad . \tag{18}$$

We construct two models of the bid-ask spread: one for transactions between dealers and clients, $\gamma^C_{i,j}$, and the other for transactions between dealers, $\gamma^D_{i,j}$. The explanatory variables are the same as in the models for dealer execution costs.

[24]Iercosan and Jiron (2017) use the same process for estimating the bid-ask spread.

Table 6: Intermediation Network and Dealer-to-Client Execution Cost

	Dependent Variable							
	Execution Cost							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	11.9999	12.3214*	12.5711*	12.6053*	6.6116	7.1010	7.8261	7.8430
Interdealer Dealer Completeness		-0.0121		-0.0126		-0.0132		-0.0124
Client Dealer Completeness		0.0147		0.0156		0.0150		0.0159
Interdealer Market Completeness			-0.0061	0.0027			-0.0122	-0.0037
Client Market Completeness			-0.0209	-0.0485			-0.0276	-0.0556
log(Dealer ‖Inventory‖)	0.4017***	0.3893***	0.4007***	0.3883**	0.3894***	0.3781**	0.3876**	0.3742**
log(‖Net Dealers Inventory‖)	-0.1585	-0.1497	-0.1565	-0.1444	-0.2898	-0.2787	-0.2854	-0.2745
log(Gross Dealers Inventory)	-1.7215*	-1.6260	-1.6213	-1.5971				
log(Gross Long Dealers Inventory)					-0.6522	-0.6242	-0.6131	-0.6118
log(Gross Short Dealers Inventory)					-0.3623	-0.2978	-0.2388	-0.2115
CDS Clearing Eligible	0.3545	0.3123	0.3473	0.3057	0.3110	0.2669	0.2984	0.2560
Number of Market Dealers	-0.0608	-0.0879	-0.1013	0.0987	-0.0631	-0.0928	-0.1368	-0.1344
Interdealer Volume Share	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001
Time Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Reference Entity Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Observations	284,008	284,008	284,008	284,008	284,008	284,008	284,008	284,008
Adjusted R^2	1.87%	1.87%	1.87%	1.88%	1.87%	1.87%	1.87%	1.87%

Note: The table presents the results of Equation (16) for the relationship among measures of network completeness, characteristics of dealer inventories, characteristics of the underlying reference entity, and the execution cost of a transaction between a client and a dealer.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

Table 7: Intermediation Network and Interdealer Execution Cost

	Dependent Variable							
	Execution Cost							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	0.1714	0.6737	0.1877	0.5627	0.0991	0.5305	0.1262	0.4023
Interdealer Dealer Completeness		0.0078		0.0092		0.0078		0.0092
Client Dealer Completeness		-0.0409***		-0.0422***		-0.0408***		-0.0422***
Interdealer Market Completeness			-0.0006	-0.0078			-0.0007	-0.0079
Client Market Completeness			0.0036	0.0746***			0.0034	0.0745***
log(Dealer ‖Inventory‖)	0.0043	0.0774	0.0042	0.0767	0.0042	0.0774	0.0042	0.0766
log(‖Net Dealers Inventory‖)	-0.0035	-0.0063	-0.0038	-0.0136	-0.0071	-0.0154	-0.0072	-0.0179
log(Gross Dealers Inventory)	-0.0625	-0.1748	-0.0605	-0.1959**				
log(Gross Long Dealers Inventory)					-0.0318	-0.0888*	-0.0299	-0.0652
log(Gross Short Dealers Inventory)					-0.0213	-0.0673	0.0034	-0.1117*
CDS Clearing Eligible	0.0537***	0.1345***	0.0531***	0.1336***	0.0533***	0.1338***	0.0527***	0.1327***
Number of Market Dealers	0.0118	0.0285	0.0104	0.0276	0.0119	0.0288	0.0100	0.0269
Interdealer Volume Share	0.0000	-0.0003	0.0000	-0.0002	0.0000	-0.0003	0.0000	-0.0002
Time Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Reference Entity Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1,011,154	1,011,154	1,011,154	1,011,154	1,011,154	1,011,154	1,011,154	1,011,154
Adjusted R^2	0.01%	0.10%	0.01%	0.10%	0.01%	0.10%	0.01%	0.10%

Note: The table presents the results of Equation (17) for the relationship among measures of network completeness, characteristics of dealer inventories, characteristics of the underlying reference entity, and the execution cost of a transaction between dealers.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

$$
\begin{aligned}
\gamma^{\mathrm{C}}_{i,j,t} =& \beta_0 + \beta_1 \mathrm{K}^{\mathrm{D}}_{j,t-1} + \beta_2 \mathrm{K}^{\mathrm{C}}_{j,t-1} + \beta_3 \mathrm{k}^{\mathrm{D}}_{i,j,t-1} + \beta_4 \mathrm{k}^{\mathrm{C}}_{i,j,t-1} + \beta_5 \log(\|x_{i,j,t}\|) + \beta_6 \log(\|X_{j,t}\|) \\
&+ \beta_7 \log(Y_{j,t}) + \beta_8 \mathbb{1}^{\text{Clearable}}_{j,t} + \beta_9 |\mathcal{D}_{j,t}| + \beta_{10} \lambda^{\mathrm{D}}_{j,t}/\lambda_{j,t} + \beta_{11-92} \mathbb{1}^{\mathrm{M/Y}} + \beta_{93-389} \mathbb{1}^{\mathrm{R}}_j + \epsilon,
\end{aligned}
\tag{19}
$$

$$
\begin{aligned}
\gamma^{\mathrm{D}}_{i,j,t} =& \beta_0 + \beta_1 \mathrm{K}^{\mathrm{D}}_{j,t-1} + \beta_2 \mathrm{K}^{\mathrm{C}}_{j,t-1} + \beta_3 \mathrm{k}^{\mathrm{D}}_{i,j,t-1} + \beta_4 \mathrm{k}^{\mathrm{C}}_{i,j,t-1} + \beta_5 \log(\|x_{i,j,t}\|) + \beta_6 \log(\|X_{j,t}\|) \\
&+ \beta_7 \log(Y_{j,t}) + \beta_8 \mathbb{1}^{\text{Clearable}}_{j,t} + \beta_9 |\mathcal{D}_{j,t}| + \beta_{10} \lambda^{\mathrm{D}}_{j,t}/\lambda_{j,t} + \beta_{11-92} \mathbb{1}^{\mathrm{M/Y}} + \beta_{93-389} \mathbb{1}^{\mathrm{R}}_j + \epsilon.
\end{aligned}
\tag{20}
$$

Table 8 presents the results for the magnitude of the bid-ask spread for transactions between dealers and clients. The table shows that the bid-ask spread is smaller for markets with many dealers, likely due to increased competition. The bid-ask spread also declines with the size of the inventory of individual dealers, suggesting that clients can achieve better prices when dealers hold large inventories. The bid-ask spread increases with the total, aggregate, gross dealer inventory, although not with the net dealer inventory. This result suggests that bid-ask spreads between dealers and clients increase with the volume of trading, even when trading is balanced, potentially due to costs associated with dealers holding more inventory on their balance sheet. In line with Proposition 5, the network measures indicate that the dealer-to-client bid-ask spreads are smaller when individual dealers are better connected to other dealers. This result is consistent with results in the literature for the corporate bond market that show that more central dealers are better able to share risk and can pass along this additional liquidity, in the form of smaller bid-ask spreads, to their clients.

Table 9 presents the results for the magnitude of the bid-ask spread for interdealer transactions. Similar to transactions between dealers and clients, the table shows that the bid-ask spread is smaller for markets with many dealers. The bid-ask spread increases with the aggregate market inventory. Additionally, it increases by 95-103 basis points when CDS contracts are eligible for clearing, a further indication that clearing may increase costs for dealers. Among the network measures, we do not find support for Proposition 5 as the completeness of the intermediation network of individual dealers is not significant. However, there is support for Proposition 6, as the market completeness measures are significant for both the interdealer and the dealer-to-client networks. In both cases, we find that the more well-connected a trade network is, the narrower

Table 8: Intermediation Network and Dealer-to-Client Bid-Ask Spreads

	Dependent Variable							
	Bid-Ask Spread							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	8.1679	12.5522**	12.6502*	14.4924**	6.0783	10.8390*	11.4561*	13.2079*
Interdealer Dealer Completeness		-0.0551***		-0.0468***		-0.0547***		-0.0462***
Client Dealer Completeness		0.0000		-0.0008		0.0001		-0.0008
Interdealer Market Completeness			-0.0695***	-0.0381			-0.0694***	-0.0385
Client Market Completeness			-0.0199	-0.0227			-0.0108	-0.0138
log(Dealer ‖Inventory‖)	-0.5635***	-0.4793***	-0.5743***	-0.4963***	-0.5685***	-0.4849***	-0.5785***	-0.5014***
log(‖Net Dealers Inventory‖)	-0.3215*	-0.3028*	-0.3195*	-0.3036*	-0.1162	–0.0976	-0.1001	-0.0915
log(Gross Dealers Inventory)	1.2448*	1.5369***	2.0847***	2.1290***				
log(Gross Long Dealers Inventory)					1.5825**	1.6221***	1.8043***	1.7378***
log(Gross Short Dealers Inventory)					-0.1898	0.0175	0.3523	0.2936
CDS Clearing Eligible	-0.1347	-0.1967	-0.1893	-0.2171	-0.1256	-0.1873	-0.1778	-0.2059
Number of Market Dealers	0.0264	-0.1215	-0.3314***	-0.3014**	0.0135	-0.1320	-0.3368***	-0.3077**
Interdealer Volume Share	-0.0049	-0.0044	-0.0044	-0.0042	-0.0049	-0.0044	-0.0044	-0.0042
Time Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Reference Entity Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Observations	284,008	284,008	284,008	284,008	284,008	284,008	284,008	284,008
Adjusted R^2	5.00%	5.06%	5.03%	5.07%	5.02%	5.08%	5.04%	5.09%

Note: The table presents the results of Equation (19) for the relationship among measures of network completeness, characteristics of dealer inventories, characteristics of the underlying reference entity, and the bid-ask spread of a transaction between a client and a dealer.
Source: Authors' calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation.

the bid-ask spread for CDS contracts on that reference entity. The results highlight that well-connected networks allow for lower trading costs and are consistent with more complete networks being associated with larger risk-sharing capacity by intermediaries.

Table 9: Intermediation Network and Interdealer Bid-Ask Spreads

	Dependent Variable							
	Bid-Ask Spread							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	15.0386***	16.1376***	21.1550***	21.2713***	14.4430***	15.6112***	21.4461***	21.5435***
Interdealer Dealer Completeness		-0.0135		-0.0029		-0.0132		-0.0028
Client Dealer Completeness		-0.0025		-0.0037		-0.0024		-0.0038
Interdealer Market Completeness			-0.0694***	-0.0673***			-0.0680***	-0.0660***
Client Market Completeness			-0.0941**	-0.0884*			-0.0860	-0.0802
log(Dealer ‖Inventory‖)	-0.0424	-0.0037	-0.0496	-0.0339	-0.0464	-0.0083	-0.0517	-0.0362
log(‖Net Dealers Inventory‖)	-0.2575**	-0.2565**	-0.2442**	-0.2449**	-0.1298	-0.1302	-0.1184	-0.1196
log(Gross Dealers Inventory)	0.3847	0.4419	1.2815***	1.2574***				
log(Gross Long Dealers Inventory)					0.8887***	0.8884***	1.0362***	1.0279***
log(Gross Short Dealers Inventory)					-0.5034	-0.4556	0.1152	0.1017
CDS Clearing Eligible	1.0337***	1.0180***	0.9396***	0.9445***	1.0325***	1.0175***	0.9453***	0.9504***
Number of Market Dealers	-0.1540***	-0.1903***	-0.5636***	-0.5582***	-0.1623***	-0.1976***	-0.5587***	-0.5535***
Interdealer Volume Share	0.0064***	0.0068***	0.0071***	0.0071***	0.0062***	0.0063***	0.0070***	0.0070***
Time Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Reference Entity Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1,011,154	1,011,154	1,011,154	1,011,154	1,011,154	1,011,154	1,011,154	1,011,154
Adjusted R^2	9.37%	9.38%	9.44%	9.44%	9.38%	9.39%	9.44%	9.45%

Note: The table presents the results of the Equation (20) for the relationship among measures of network completeness, characteristics of dealer inventories, characteristics of the underlying reference entity, and the bid-ask spread of a transaction between dealers.

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

6 Conclusions

We presented a model that predicts that the density of intermediation trade networks affects the liquidity of over-the-counter markets, and we empirically examined this prediction using data from the single-name CDS market. Our results indicate a strong relationship between the market's intermediation network and liquidity provision by dealers, both individually and collectively, as seen through trade volume, dealer inventory, and the cost of trade, measured by both execution cost and bid-ask spreads.

From a dealer intermediation network perspective, our results are generally consistent with the predictions of the model, and with the previous empirical literature on debt markets. However, our work does uncover several findings that are distinct from those of prior studies in the literature. Notably, we find a dealer's willingness to provide liquidity, in terms of taking increased inventory on their balance sheet, is positively associated with how well-connected the dealer is to its clients and other dealers. We also find that dealer execution costs are driven primarily by a dealer's transactions with clients, while dealer bid-ask spreads are primarily driven by the ability of the dealer to intermediate trade with other dealers, rather than with clients. Focusing on the distinction between dealer-to-client and interdealer transactions, when considering a dealer's interdealer execution cost, we find that the execution cost declines as the proportion of relationships a dealer maintains with clients increases. However, we also find that, perhaps surprisingly, this execution cost is not related to the dealer's relationships with other dealers. In addition, the bid-ask spread a dealer receives with its clients declines as the completeness of its interdealer network increases, while its interdealer bid-ask spread is not related to its interdealer network.

Our findings highlight several differences between how a market intermediation network, and an individual dealer's intermediation network, impacts liquidity and our findings also challenge theoretical predictions that more complete markets always lower execution costs and narrow bid-ask spreads. We find that a dealer's execution cost when trading with other dealers increases as the completeness of the dealer-to-client network at the market level increases. This finding suggests that, potentially, as the dealer-to-client network becomes more complete, a dealer's need to intermediate inventory within the interdealer network declines and dealers may charge higher execution costs to one another.

Since our study focuses on the single-name CDS markets during a period when several regulatory reforms were enacted, our results help shed light on the importance of trading relationships in maintaining market liquidity. We find several shifts in dealer behavior during this period, as interdealer trade and dealer participation declined and inventory management tightened. All these shifts are consistent with a decline in market liquidity. Although the focus of this paper is on the relationship between network changes – and specifically network completeness – and liquidity, rather than on the relationship between regulations and changes in intermediation networks, our paper does highlight the need for policymakers to consider how regulations lead to changes in counterparty relationships. Specifically, our network measures can be used to study the potential consequences of new regulations or the failure of an intermediary. For example, consider regulations for trading index CDS contracts that were mandated to clear centrally and trade on swap execution facilities beginning in 2013. These two regulations reduce collateral for centrally cleared transactions and centralize trade. Given theoretical predictions on the effect of these regulations, our measures and methods could provide empirical insight into both the evolution of intermediation and the impact on liquidity. Whether the benefits of these mandates outweigh the costs remains an open question.

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A Regression Variable Definitions

Table A.1: Variable Dictionary

CDS $\text{Spread}_{j,t}$	Markit spread for reference entity j at time period t
ΔCDS $\text{Spread}_{j,t}$	Change in Markit spread for reference entity j, between time period t and $t-1$
CDS Transaction $\text{Spread}_{i,j,t}$	CDS spread of transaction of firms i on reference entity j at time period t
Recovery $\text{Rate}_{j,t}$	Markit estimated recovery rate for reference entity j at time period t
Index λ_t^{C}	Total dealer-to-client volume of index CDS at time period t
Bond $\lambda_{j,t}$	Total volume of underlying bond of reference entity j at time period t
$\mathbb{1}_{j,t}^{\text{Clearable}}$	Eligible to clear indicator variable for reference entity j at time period t capturing clearing fixed effects
$\mathbb{1}^{\text{M}}$	Month indicator variables capturing seasonality fixed effects
$\mathbb{1}^{\text{M/Y}}$	Year-month indicator variables capturing time fixed effects
$\lambda_{j,t}^{\text{C}}$	Client CDS volume for reference entity j at time period t
$\lambda_{i,j}^{\text{D}}$	Interdealer CDS volume for reference entity j at time period t
$\lambda_{j,t}$	Total CDS volume for reference entity j at time period t
$\lambda_{j,t}^{\text{D}}/\lambda j,t$	Share of Interdealer CDS volume over total CDS volume for reference entity j at time period t
$\mathcal{D}_{j,t}$	Set of market dealers for reference entity j at time period t
$\mathcal{C}_{j,t}$	Set of market clients for reference entity j at time period t
$x_{i,j,t}$	Absolute value of net inventory of individual dealer i for reference entity j at time period t
$\text{X}_{j,t}$	The aggregate net inventory of dealers for reference entity j at time period t
$\text{Y}_{j,t}$	The gross net inventory of dealers for reference entity j during time period t
$\text{K}_{j,t}^{\text{D}}$	Market's network completeness of interdealer network of reference entity j at time period t
$\text{K}_{j,t}^{\text{C}}$	Market's network completeness of dealer-to-client network of reference entity j at time period t
$\text{k}_{j,t}^{\text{D}}$	Dealer's network completeness with other dealers of reference entity j at time period t
$\text{k}_{j,t}^{\text{C}}$	Dealer's network completeness with clients of reference entity j at time period t
$\mu_{i,j,t}^{\text{C}}$	Execution cost relative to Markit spread for dealer-to-client transactions for dealer i, reference entity j during time period t
$\mu_{i,j,t}^{\text{D}}$	Execution cost relative to Markit spread for interdealer transactions for dealer i, reference entity j at time period t
$\gamma_{i,j,t}^{\text{C}}$	Bid-ask spread relative to Markit spread for dealer-to-client transactions for dealer i, reference entity j at time period t
$\gamma_{i,j,t}^{\text{D}}$	Bid-ask spread relative to Markit spread for interdealer transactions for dealer i, reference entity j at time period t
$\log(\text{Dealer }\|\text{Inventory}\|_{i,j,t})$	Logarithm of the absolute value of the inventory of individual dealer i for reference entity j at time period t
$\log(\|\text{Net Dealers Inventory}\|_{j,t})$	Logarithm of the absolute value of aggregate net inventory of dealers for reference entity j at time period t
$\log(\text{Gross Dealers Inventory}\|_{j,t})$	Logarithm of the sum of the absolute values of dealer inventories for reference entity j at time period t
$\log(\text{Gross Long Dealers Inventory}_{j,t})$	Logarithm of the sum of the inventories of dealers that are long CDS contracts for reference entity j at time period t
$\log(\text{Gross Short Dealers Inventory}_{j,t})$	Logarithm of the sum of absolute value of the inventories of dealers that are short CDS contracts for reference entity j at time period t

Note: List and definition of all variables used in regression models.
Source: Authors' creation.

B Proof of Proposition 1

We prove the proposition for the ask price that maximizes a dealer's profit in the case of a decrease in the overall marginal cost to rebalance their portfolio – the other cases are similar. Recall that the dealer's expected revenue is equal to $ad_b(a)$, where a is the ask price, and $d_b(a)$ is the probability that a client would buy a unit given the ask price. Assume that the marginal cost of the transaction is given by $\tilde{c}(v+1) - \tilde{c}(v)$, where $\tilde{c}(\cdot)$ is a function that captures the dealer's cost taking into account that the dealer rebalances their position with all other dealers. This cost incorporates the increased inventory cost for the dealer that transacts with the client, the dealer's share of surplus generated through trade with other dealers, and the deadweight cost associated with the average length of the interdealer intermediation chain; i.e., $\tilde{c}(\cdot)$ is the increased inventory cost of the dealer transacting with the client minus the Shapley value that results from the rebalancing trades between the dealer transacting with the client and the remaining dealers. Each dealer chooses the ask price to maximize

$$\max_a d_b(a)\left(a - (\tilde{c}(v+1) - \tilde{c}(v))\right)$$

Defining the derivative of the maximization argument by $f(\cdot)$:

$$f(a) = d_b(a)\left(a - (\tilde{c}(v+1) - \tilde{c}(v))\right)' = d_b(a) + ad_b'(a) - d_b'(a)(c(v+1) - c(v))$$

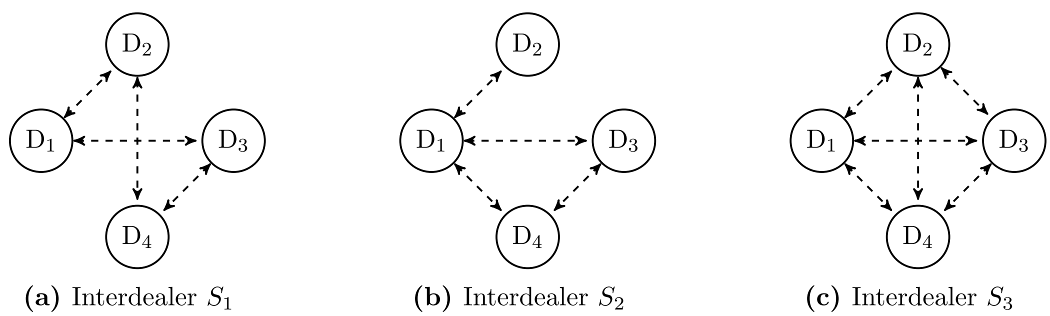
we have that, for the unique value of the ask price that maximizes the dealer's profit, a^*, $f(a^*) = 0, f'(a^*) < 0$. Since the client demand curve is downward sloping, $d_b'(\cdot) < 0$, from the definition of the function $f(\cdot)$ we have that for a small decrease in the marginal overall dealer cost; i.e., for a smaller value of $c(v+1) - c(v)$, and denoting the new function with the reduced marginal cost, $g(\cdot)$, $g(a^*) < 0$. Moreover, since the marginal cost does not depend on the ask price a, the derivative of the function $g(\cdot)$ has the same sign as the derivative of the function $f(\cdot)$, as long as the decrease in the marginal cost is small enough; i.e., we have that $g'(a^*) < 0$. We can calculate the new optimal solution for the function $g(\cdot)$ using Newton's method and the implicit function theorem to create a contraction map. The Newton method step is given by $-g(a^*)/g'(a^*) < 0$, proving that the new ask price that maximizes dealer profits, a^{**}, is smaller than the original solution a^*.

C An example network

C.1 Shapley values

We illustrate the calculation of Shapley value in an example with four dealers, $\{D_1, D_2, D_3, D_4\}$, with three sets of relationships depicted in Figure A.1. For the purpose of the example, we assume that the inventory and intermediation costs are the same for all dealers and are given by $c_{\text{inv}}(i) = i^2$ and $c_{\text{int}} = 1/(1 + 150e^{-2r})$, and that the initial inventory for all dealers is equal to zero. Now let us assume a client of dealer D_1 transacts with them and increases the dealer's inventory to $i = 12$. This means that the dealer will look to redistribute 9 units across the other three dealers.

Figure A.1: Example Interdealer Surplus Division



Note: The figure presents an interdealer trading network, where dealers, D_i, are nodes and dashed links represent the trade relationships associated with S_i.
Source: Authors' creation.

The surplus generated by redistributing the inventory costs is equal to $108 = 12^2 - 4(3^2)$. The intermediation cost associated with the average intermediation chain lengths of each network is equal to 4/3, 4/3, and 1. The final trade surplus is equal to (a) 98.5 (b) 98.5 and (c) 102.9. Table A.2 presents the marginal value of each S sub-coalition, and it helps determine the dealers' Shapley values for each network, which are (a) $\{58, 17.3, 17.3, 5.9\}$, (b) $\{64, 10.6, 11.9, 11.9\}$, and (c) $\{65.8, 12.4, 12.4, 12.4\}$

The characteristics of each network determine both the intermediation surplus and its distribution among dealers. For example, comparing the first two networks, which have the same total number of relationships, illustrates the value of a dealer's relationships relative to others: Dealer D_1 can trade directly with every other dealer and retains the majority of the surplus in (b) over (a). On the other hand, the difference in the total surplus between the last two networks is due to the lower value of intermediation costs, which is in turn due to a shorter intermediation chain.

Table A.2: Trade Surplus Coalitions

Coalitions	Inventory Cost Surplus			Intermediation Chain			Trade Surplus		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
{D_1,D_2}	72	72	72	1	1	1	68.6	68.6	68.6
{D_1,D_3}	72	72	72	1	1	1	68.6	68.6	68.6
{D_1,D_4}	0	72	72	-	1	1	0	68.6	68.6
{D_2,D_3}	0	0	0	-	-	1	0	0	0
{D_2,D_4}	0	0	0	1	-	1	0	0	0
{D_3,D_4}	0	0	0	1	1	1	0	0	0
{D_1,D_2,D_3}	96	96	96	4/3	4/3	1	87.6	87.6	91.5
{D_1,D_2,D_4}	96	96	96	4/3	4/3	1	87.6	87.6	91.5
{D_1,D_3,D_4}	96	96	96	4/3	1	1	87.6	91.5	91.5
{D_2,D_3,D_4}	0	0	0	4/3	-	1	0	0	0
{D_1,D_2,D_3,D_4}	108	108	108	4/3	4/3	1	98.5	98.5	102.9

Note: The table presents the subsets of coalitions for the networks S_1 to S_3 which are used to calculate the division of the trade surplus according to each dealer's Shapley value.
Source: Authors' creation.

While D_1 retains a lower proportion of the total surplus in (c) over (b), due to the decrease in the intermediation costs, D_1 retains a higher amount of surplus.

C.2 Bid-ask spreads

We illustrate how additional links between dealers influence bid-ask spreads using the leftmost network in figure A.1. To simplify the calculation we start with an initial inventory of zero for all four dealers. We assume that Dealer D_1 has a client that will either buy 4 units or sell 4 units, with the probability of buying given by $p_a(a) = \frac{10-a}{10}$ and the probability of selling by $p_b(b) = \frac{10+b}{10}$, where a is the dealer's ask price, and b the dealer's bid price, and we assume that a, b take values such that $0 \leq p_a, p_b \leq 1$.

For this network, if the client buys four units from dealer D_1, the inventories become D_1 : $4, D_2 : 0, D_3 : 0, D_4 : 0$. The dealers rebalance all inventories to minimize inventory costs, resulting in equal inventories across all dealers: $D_1 : 1, D_2 : 1, D_3 : 1, D_4 : 1$. The initial inventory cost across the network is 16, all borne by dealer D_1, while the final inventory cost across the network is 4, equally spread across all four dealers. Following a calculation of the value of the various coalitions, we determine that the total trade surplus is equal to 11.2. The trade surplus is divided in the following manner across the four dealers according to each dealer's Shapley values: $(6.6, 2, 2, 0.6)$. This means that dealer D_2 receives a value of 2 over their inventory cost of 1, dealer D_2 also receives

2 over their inventory cost of 1, dealer D_4 receives 0.6 over their inventory cost of 1, and dealer D_1's cost is reduced from 16 to 9.4.

Given this calculation, dealer D_1 chooses its ask price to maximize her profit; i.e., the probability of a transaction times the benefit from the transaction minus the cost induced by the transaction, $p(a)\,(4a - 9.4) = \frac{10-a}{a}\,(4a - 9.4)$. Maximizing this function with respect to the ask price a, yields an optimal ask price per unit of 6.2. Similarly, and given the symmetry of the initial inventory across dealers, the optimal bid price per unit b, is equal to -6.2.

We illustrate the influence of adding a link for dealer D_1, by modifying the leftmost network of Figure A.1. Assume that, in addition to links to dealers D_2 and D_3, dealer D_1 is also connected to dealer D_4. This additional connection results in a bigger total trade surplus for the entire network, since the average intermediation length decreases – the total trade surplus rises to 11.5. The Shapley values for dealers D_1 and D_4 increase as well, with the Shapley values for all dealers given by $(7.3, 1.4, 1.4, 1.4)$. This means that dealer D_1's cost for the transaction if 8.7 (instead of 9.4), and that dealer D_1 maximizes the function $\frac{10-a}{a}(4a - 8.7)$. The maximization yields an optimal ask price per unit, a, equal to 6.1, and similarly a bid price per unit of -6.1. This example helps illustrate how a denser network translates in a bigger benefit for those dealers that establish new connections, and a tighter bid-ask spread.