Market Structure and Transaction Costs of Index CDSs*

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Abstract

Despite a regulatory effort to promote all-to-all trading, the post-Dodd-Frank index-CDS market remains two-tiered. Dealer-to-client trades have higher transaction costs than interdealer trades. The difference is entirely explained by the higher, largely permanent, price impact of client trades. However, transaction costs of interdealer trades vary significantly across trading protocols. Mid-market matching and workup—both characterized by execution risk—incur the smallest costs. Dealer-to-client trades typically execute well inside the spread quoted on the interdealer limit order book. Thus, clients who value immediacy could not improve execution with marketable interdealer orders. This may explain the endurance of the two-tiered market structure.

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1 Introduction

The index credit default swap (CDS) market constitutes an important component of the corporate credit market. Index CDSs allow banks, asset managers, and other institutional investors to efficiently hedge and trade aggregate credit risk in the economy. Unlike single-name CDSs, index CDSs have remained popular since the financial crisis with tens of billion dollars of notional amount traded on a daily basis. Nevertheless, little is known about the cost of trading in this important market.

The index CDS market is also interesting as a test case of how recent regulation introduced in the wake of the financial crisis affects the structure of swap markets. Since its inception in 2003, the index CDS market has operated as a classic two-tiered over-the-counter (OTC) market in which global derivatives dealers provide liquidity to clients in the dealer-to-client (D2C) segment of the market, and dealers trade among themselves in the interdealer (D2D) segment of the market. New swap market regulation following the Dodd-Frank Act had the potential to change this market structure by mandating trades in the most liquid index CDSs to be executed on so-called swap execution facilities (SEFs).[1] These regulated trading platforms are required to offer trading in order books, which opens up the market to all-to-all trading where clients can compete with dealers for liquidity provision. However, the regulation also allows for trading on SEFs via request for quote (RFQ) provided that at least three dealers are put in competition for trades.[2] Interestingly, several years after the new regulation was fully implemented, all-to-all trading has yet to materialize. Instead, the two-tiered market structure persists, with D2C trades taking place on one group of SEFs (almost exclusively via name-disclosed RFQs) and D2D trades taking place on another group

[1] Other key elements of the new swap market regulation are post-trade transparency via the immediate public dissemination of trades as well as central clearing of index CDSs with standardized contract terms.

[2] RFQ is an electronic trading protocol that enables requesting executable prices for a given notional amount from multiple dealers simultaneously. Typically, the quote requester has to reveal his identity (the RFQ is name-disclosed) and specify whether he wants to buy or sell. This closely mimics the traditional way of trade execution in OTC markets when quotes are requested from a single dealer only.

of SEFs (via a diverse set of trading protocols).[3] All the SEFs in the latter group are run by interdealer brokers (IDBs).

From a regulatory and market design perspective it is important to understand the endurance of this bifurcated market structure. On the one hand, it could suggest that this is indeed the optimal structure of a market in which clients trade relatively infrequently but in very large sizes; see, e.g., Giancarlo (2015).[4] On the other hand, some market participants have accused dealers of resisting a transition to all-to-all trading in order to limit competition from non-dealer liquidity providers; see, e.g., Managed Funds Association (2015).

Motivated by these issues, the paper has three related objectives. First, we characterize the two-tiered structure of the post-Dodd-Frank index CDS market. Second, we analyze transaction costs and price impacts across market segments and trading protocols. Third, we estimate dealer profits from liquidity provision to clients.

We use transaction data from October 2, 2013 (the date on which the first SEFs started operating) to October 16, 2015, and we focus on the two most popular credit indices, CDX.IG and CDX.HY, which cover the investment-grade and high-yield components, respectively, of the North American corporate credit market. The transaction data include execution timestamps, transaction prices, and trade sizes up to certain notional caps. In addition, we develop algorithms that allow us to identify, for each trade, the SEF on which the trade took place and the type of trade (outright trade, index roll, curve trade, or delta hedge of an index swaption or tranche swap). The SEF on which the trade took place in turn reveals whether the trade is D2C or D2D.[5]

[3] Referring to both the index CDS and the interest rate swap markets, a recent article summarizes the current situation as "...dealer banks still trade together privately in one segment of the market and the buy side still executes via RFQ to the dealers in another. Proponents of this view say that nothing really changed in terms of how firms execute swaps except that the buy side has gone from RFQ-ing one dealer to RFQ-ing three. This appears to be in stark contrast to the all-to-all trading model envisioned for the swaps markets by regulators under Dodd-Frank." See "SEFs: A Market Divided," *Profit & Loss*, October 22, 2015.

[4] For example, for CDX.IG, one of the two most actively traded credit indices, there are, on average, 114 client trades per day with a median trade size of USD 50 million.

[5] Because we identify D2C and D2D trades based on the SEF on which the trade took place, our sample is limited to the period during which SEFs were in operation and to trades that are executed on SEFs.

Trading volumes are large. The average daily notional amounts traded in the D2C segment are USD 9.843 billion for CDX.IG and USD 3.705 billion for CDX.HY. In the D2D segment, the corresponding figures are USD 1.354 billion and USD 0.402 billion. Outright trades in five-year CDSs on the most recently issued (on-the-run) index account for the majority of trading volume. These trades are the focus of the paper.

We measure transaction cost by the effective half-spread, which is the difference between the transaction price and the mid-point of contemporaneous quotes to buy or sell protection (henceforth the mid-quote). We measure price impact as the change in the mid-quote over a period of approximately 15 minutes following a trade. Throughout the paper, we express transaction prices and quotes in terms of par spreads. For D2C trades, we compute effective half-spreads and price impacts using intraday quotes from Markit, which are composites of indicative quotes sent by dealers to clients. For D2D trades, we use a unique data set of executable inside quotes on the limit order book of the main IDB SEF, the GFI Swaps Exchange (GFI SEF). Transaction costs of D2C trades are higher than those of D2D trades, on average. For CDX.IG, average transaction costs of D2C and D2D trades are 0.138 basis points (bps) and 0.098 bps, respectively, with the difference of 0.040 bps being statistically significant. The corresponding figures for CDX.HY are 0.676 bps and 0.494 bps, with the difference of 0.181 bps again being statistically significant.[6] This difference in transaction costs can be entirely explained by the fact that D2C trades have, on average, a higher price impact than D2D trades. For CDX.IG, average price impact is 0.042 bps higher for D2C trades and for CDX.HY, average price impact is 0.246 bps higher for D2C trades.

We also investigate how trade characteristics and market conditions affect transaction costs and price impacts. Trade-by-trade regressions show that transaction costs and price

[6]To put these transaction costs into perspective, we translate the par-spread cost of each trade into a dollar cost paid upfront per 100 dollar notional value. For CDX.IG, average dollar costs of D2C and D2D trades are 0.66 cents and 0.48 cents, respectively. The corresponding figures for CDX.HY are 3.04 cents and 2.24 cents. For comparison, Adrian, Fleming, Shachar, and Vogt (2017) report that the average bid-offer half-spread on the main interdealer limit order book for the five-year on-the-run Treasury note is approximately 0.40 cents per 100 dollar notional value.

impacts increase with trade size, bid-offer spreads, and volatility implied by index swaptions; i.e., options on index CDSs. However, our findings regarding differences in transaction costs and price impacts of D2C and D2D trades are robust to controlling for these determinants.

Next, we analyze the dynamic interaction between trades and mid-quotes across the two market segments using a cointegrated vector autoregressive (VAR) model in the spirit of Hasbrouck (1995), which accounts for quote adjustments that correct temporary deviations from mid-quote parity (both D2C and D2D quotes ultimately reflect the credit risk of the same index constituents). The model allows to distinguish between permanent (information-driven) and transitory (inventory-driven) price impact and to quantify the relative importance of trades for price discovery. In line with our findings based on the above-mentioned 15-minute price impact measure, the model-implied price impact is higher for D2C trades. In addition, price impact is largely permanent. The relatively high permanent price impact of the average D2C trade is suggestive of clients trading on information. This likely reflects the institutional nature of the index CDS market in which clients are professional investors who may have private information about the credit risk of certain index constituents (see, e.g., Acharya and Johnson (2007) and Ivashina and Sun (2011)) or may have an advantage over dealers in interpreting public information in relation to the aggregate credit risk in the economy.[7] The relatively low permanent price impact of the average D2D trade is suggestive of dealers mainly using the interdealer market to manage their inventory risk (as documented, for instance, by Reiss and Werner (1998) for the equity market). Consistent with this, we find one-way Granger causality from D2C trades to D2D trades. In terms of price discovery, D2C trades play a more important role than D2D trades.

While virtually all D2C trades are executed via RFQs, a number of different trading protocols are used in the interdealer market. We refine the characterization of the interdealer

[7] In support of superior information processing by institutional investors, Hendershott, Livdan, and Schürhoff (2015) show that institutional order flow predicts the occurrence and sentiment of news as well as news-announcement-day equity market returns.

market by investigating how transaction costs and price impacts on the GFI SEF vary across trading protocols. In addition to a standard limit order book, this SEF offers two trading protocols—mid-market matching and workup—that facilitate trade by means of size discovery where size orders are matched at a known fixed price (see, e.g., Duffie and Zhu (2017)).[8] In contrast to standard market orders, execution of orders for matching and workup is uncertain. Mid-market matching is the dominant trading protocol; for CDX.IG and CDX.HY, it accounts for 52.2% and 58.7%, respectively, of the trading volume. Workup is also frequently used and accounts for 19.9% and 15.5%, respectively, while trades in the limit order book account for 19.2% and 15.8%.

Trades in the limit order book have high average transaction costs and price impacts, with the average price impacts exceeding those of D2C trades. In contrast, mid-market matches have significantly lower average transaction costs and price impacts. This is consistent with Zhu's (2014) venue-selection model in which liquidity traders prefer a mid-point dark pool (roughly equivalent to mid-market matching) that offers price improvement but does not guarantee execution, while informed traders prefer the certainty of executing against limit orders. By design, a workup is initiated by a trade in the limit order book and occurs at the same price. However, the additional price impact of a workup—beyond that of the initiating trade—is close to zero, on average. The upshot is that the low average transaction cost and price impact of D2D trades mask significant heterogeneity across trading protocols; size-discovery protocols attract liquidity-motivated trading, while trades in the limit order book appear relatively informed—even more so than the average D2C trade.

Finally, we estimate dealer profits from liquidity provision to clients. Assuming that

[8]The two trading protocols differ in how the price is fixed, for how long orders can be matched, and what information about unfilled interests is available to market participants. In the case of mid-market matching, the price is fixed by a broker, orders can be matched until the next time the broker resets the price, and market participants are informed when there is interest for matching. The direction and size of interests are not revealed. In the case of workup, the price is fixed by an initiating trade in the limit order book, orders can be matched for a short period of time following the initiating trade, and market participants are informed about the direction and size of interests.

dealers immediately close D2C trades at the price that is quoted for mid-market matching, estimated daily profits are USD 0.437 million for CDX.IG and USD 0.811 million for CDX.HY. However, assuming instead that dealers immediately close positions at the inside quotes on the limit order book of the GFI SEF, estimated profits are negative. Because of the execution risk associated with mid-market matching, this suggests that dealers only make profits through their willingness to bear inventory risk.

From the perspective of clients who value immediacy, our results show that the current market structure delivers very low transaction costs. The prices that clients obtain via name-disclosed RFQs are typically better than the contemporaneous inside quotes on the limit order book of the GFI SEF. The average price improvements are 0.229 bps for CDX.IG and 1.291 bps for CDX.HY, and price improvements are strictly positive for 95.8% and 96.4% of the trades in CDX.IG and CDX.HY, respectively.[9] The price improvements are sizeable when put in relation to the average transaction costs of D2C trades reported above. This suggests that the two-tiered market structure—at least when combined with regulatory measures limiting dealer market power, such as post-trade transparency and the requirement to put a minimum number of dealers in competition for trades—constitutes a viable alternative to all-to-all trading in swap markets.[10]

[9] This is different from the spot FX market in which D2C trades typically exhibit a positive markup relative to executable inside quotes in the interdealer market (see, e.g., Bjønnes, Kathitziotis, and Osler (2016)). In contrast to the index CDS market, the spot FX market is largely unregulated (e.g., there is no post-trade transparency) and the use of multi-dealer RFQs is less prevalent because D2C trading increasingly takes place on single-dealer trading platforms (see, e.g., King, Osler, and Rime (2012)).

[10] Proponents of bringing all market participants onto one limit order book typically argue that it would (i) increase quote competition among dealers and (ii) allow clients to occasionally supply liquidity via limit orders thereby lowering overall transaction costs (although at the cost of execution risk). However, a limit order book arguably works best when trading is continuous and it is not necessarily optimal when trading is more episodic as is the case for index CDSs. For instance, Barclay, Hendershott, and Kotz (2006) document a precipitous drop in electronic trading (via limit order books) when Treasuries go off-the-run and trading volumes decline.

1.1 Related Literature

The paper relates to a number of recent studies of how various provisions of the Dodd-Frank Act affect swap market liquidity. Loon and Zhong (2016) show that post-trade transparency and central clearing have a positive impact on liquidity in the index CDS market. Benos, Payne, and Vasios (2016) show that pre-trade transparency (the mandate to trade on SEFs) has a positive impact on liquidity in the interest rate swap market. In contrast, we focus on the structure of the index CDS market after the full implementation of the new swap market regulation and analyze transaction costs across market segments and trading protocols.

The paper also relates to studies of transaction costs in the related markets for single-name CDSs and corporate bonds, both of which function as traditional OTC markets with relatively high search costs. For single-name CDSs, Biswas, Nikolova, and Stahel (2015) report average effective half-spreads in upfront terms of 14 bps for D2C trades in typical sizes of approximately USD 5 million. For a recent sample of corporate bonds, Harris (2015) reports average relative effective half-spreads in price terms of 39 bps for institutional-sized D2C trades.[11] For comparison, for D2C trades in CDX.IG and CDX.HY, average effective half-spreads in upfront terms are 0.66 bps and 3.04 bps, respectively, and average relative effective half-spreads in price terms are 0.66 bps and 2.87 bps. As such, transaction costs of index CDSs are about an order of magnitude lower than those of single-name CDSs and corporate bonds. Also, in contrast to virtually all corporate bond studies but consistent with standard models of asymmetric information and inventory control, we find that transaction costs increase with trade size.

Finally, the paper relates to empirical studies of size-discovery trading protocols. Size discovery is widely used in the equity market (in the form of mid-point dark pools) and in the

[11] We benchmark against Harris (2015) because his sample period overlaps with ours and his method of computing transaction costs is similar to ours. Earlier studies using different methodologies also report large transaction costs of corporate bonds; see, e.g., Edwards, Harris, and Piwowar (2007), Goldstein, Hotchkiss, and Sirri (2007), and Hendershott and Madhavan (2015).

Treasury market (in the form of workup). In both markets, the trades that occur through size discovery tend to be less informed; see, e.g., Comerton-Forde and Putniņš (2015) and Fleming and Nguyen (2015). We provide the first analysis of size discovery in swap markets. In addition, we study a trading platform that offers two size-discovery protocols—mid-market matching and workup—providing insights into the relative importance and different impacts of the two trading protocols.

Theoretically, a two-tiered structure can arise endogenously in OTC markets, for instance, as a result of trade competition and inventory balancing (see, e.g., Atkeson, Eisfeldt, and Weill (2013) and Wang (2016)). Vogler (1997) and Viswanathan and Wang (2004) compare the prices that clients get in a two-tiered structure with those that they get in an auction market, taking the structure of the market as given. Dunne, Hau, and Moore (2015) model price formation in a two-tiered market structure but also take the structure as given. In contrast, Babus and Parlatore (2017) compare client welfare and the efficiency of trading in two-tiered and centralized structures when the market structure is endogenously determined.[12]

The paper is organized as follows: Section 2 describes the structure of the index CDS market and the regulatory reforms set forth by the Dodd-Frank Act. Section 3 discusses the data and the identification algorithms. Section 4 compares D2C and D2D transaction costs and investigates how transaction costs vary with trade characteristics and market conditions. Section 5 analyzes the dynamics of trades and quotes using a cointegrated VAR model. Section 6 compares D2D transaction costs across trading protocols. Section 7 estimates dealer profits from liquidity provision to clients and quantifies price improvements. Section 8 concludes. Data-related details and robustness checks are contained in an Internet Appendix.

[12] Assuming a two-tiered market structure Malamud and Schrimpf (2016) derive the equilibrium markups charged by dealers to clients and study the implications for the transmission of monetary policy.

2 The Index CDS Market

This section describes index CDSs and the structure of the market in which these contracts trade. Furthermore, it discusses regulatory reforms set forth by the Dodd-Frank Act.

2.1 Index Credit Default Swaps

An index CDS is a standardized credit derivative contract on a diversified index of reference entities (typically, companies). Over the life of the contract, the credit protection seller provides default protection on each index constituent and, in return, receives periodic premium payments according to the "fixed spread" of the contract. At initiation, counterparties exchange an upfront amount equal to the present value of the contract. However, standard market practice is to quote the contract either in terms of "spread" or "price." The price is one minus the upfront amount per dollar of notional and the quoted spread is obtained from the upfront using the ISDA CDS Standard Model.[13] We use the spread quoting convention throughout unless stated otherwise. Typically, contract tenors between one and ten years can be traded but the five-year contract tenor is the most liquid.

Twice a year, on the so-called index roll dates in March and September, a new index—or, more precisely, a new series of an index—is launched, with companies being revised according to credit rating and liquidity criteria.[14] Companies that fail to maintain a credit rating within a specified range, due to either up- or downgrades, and companies whose single-name CDSs have deteriorated significantly in terms of their trading activity are replaced by the most actively traded companies meeting the credit rating requirements. Typically, liquidity is concentrated in the most recently launched index series, which is referred to as the on-the-

[13] In short, using the ISDA CDS Standard Model and assuming a constant recovery (40% for CDX.IG and 30% for CDX.HY), a constant default intensity can be implied from the quoted upfront and the fixed spread. Then using that implied intensity and the same standard model, the quoted spread is obtained as the fixed spread that would require no upfront payment.

[14] An index's series number uniquely determines the reference entities in the index.

run index. All previously launched index series are referred to as off-the-run indices.

The administrator of the most popular credit indices is Markit, and its benchmark credit indices of investment-grade and high-yield credit risk in North America are CDX.IG and CDX.HY, respectively. The former comprises 125 North American companies with investment-grade credit ratings and the latter comprises 100 North American companies with non-investment-grade credit ratings. These indices are the focus of the paper.

2.2 Pre-Dodd-Frank Market Structure

Index CDSs used to be traded in a relatively opaque two-tiered OTC market. In the D2C segment of the market, dealers provided liquidity to their institutional clients. D2C trades were either negotiated over the phone or executed electronically on trading platforms, such as MarketAxess or Tradeweb, where trade execution was typically via name-disclosed RFQs.

In the D2D segment of the market, dealers traded with each other typically involving IDB intermediation. D2D trades were either voice brokered or executed electronically using a range of order book functionalities. IDB intermediation guaranteed that trades were executed anonymously and that access to the interdealer market was restricted to dealers.

2.3 The Dodd-Frank Act and Current Market Structure

The Dodd-Frank Act tasked the U.S. Commodity Futures Trading Commission (CFTC) with regulating the index CDS market in order to promote financial stability as well as post- and pre-trade transparency. Pursuing these objectives, the CFTC enacted a clearing requirement for index CDSs with standardized contract terms as well as a reporting requirement and a trade execution requirement.[15]

The reporting requirement mandates real-time trade reporting of all index CDS trades

[15] See Part 50, Part 43, and Part 37 of Chapter I of Title 17 of the Code of Federal Regulations (17 CFR) and Section 2(h) of the Commodity Exchange Act (CEA).

to so-called swap data repositories (SDRs). SDRs publicly disseminate the received transaction data; dissemination is immediate unless the trade qualifies as a block in which case dissemination is delayed by at least 15 minutes.[16]

The trade execution requirement mandates that the most liquid index CDSs trade on SEFs and via one of two trading functionalities: an order book or an RFQ that is transmitted to at least three other market participants on the SEF.[17] Since the trade execution requirement took effect, trades in five-year on-the-run and immediate off-the-run index CDSs on CDX.IG and CDX.HY have been subject to the requirement.[18] Block trades are exempt from the trade execution requirement.

The implementation of Dodd-Frank Act provisions for index CDSs was rolled out in stages over a period of about one year. For dealers the reporting requirement took effect on December 31, 2012 and the clearing requirement took effect on March 11, 2013. By the time the first SEFs started operating on October 2, 2013, the trade reporting and clearing requirements were in effect for all market participants. Finally, the trade execution requirement took effect on February 26, 2014. Appendix A provides a timeline with additional details concerning the CFTC's implementation of Dodd-Frank Act provisions.

Through the introduction of SEFs and the requirement that they offer trading in order books, the new regulation had the potential to open up the index CDS market to all-to-all trading.[19] However, several years into the new regulatory regime, the index CDS market

[16] Block trades have notional amounts that exceed certain minimum block sizes and are exempt from immediate dissemination to protect liquidity providers in block-sized trades from front running. Minimum block sizes depend on the par spread and contract tenor (see Appendix F to Part 43 of Chapter I of 17 CFR for details).

[17] The regulatory definition of an order book resembles that of a limit order book but it is slightly more general. Specifically, an order book is a "... trading system or platform in which all market participants in the trading system or platform have the ability to enter multiple bids and offers, observe or receive bids and offers entered by other market participants, and transact on such bids and offers" (see §37.3(a)(3) of Chapter I of 17 CFR). For an interim one-year period, it was sufficient to transmit RFQs to at least two other participants.

[18] In addition, trades in five-year on-the-run and immediate off-the-run index CDSs on iTraxx Europe and iTraxx Europe Crossover are subject to the trade execution requirement. iTraxx Europe and iTraxx Europe Crossover are Markit's benchmark credit indices of investment-grade and high-yield credit risk in Europe.

[19] Implicitly, the CFTC had hoped that the introduction of SEFs would push the index CDS market as well as other active OTC derivatives markets towards all-to-all trading. For instance, when discussing the benefits of SEF rules, the CFTC stated that the "...rules provide for an anonymous but transparent order book that

remains two-tiered and all-to-all trading has yet to materialize. The D2C segment of the market migrated onto SEFs run by incumbent operators of D2C trading platforms where the vast majority of trades are executed via name-disclosed RFQs. These are Bloomberg SEF, ICE Swap Trade, MarketAxess SEF, and TW SEF; collectively called D2C SEFs. The D2D segment of the market migrated onto SEFs run by IDBs where trades are executed via a diverse set of trading protocols that qualify as order book for regulatory purposes. These are GFI SEF, ICAP SEF, tpSEF, and Tradition SEF; collectively called IDB SEFs.

Several reasons have been given for the persistence of the two-tiered market structure. At one end of the spectrum, some observers argue that this is the optimal structure of a market in which clients trade relatively infrequently but in very large sizes (see, e.g., Giancarlo (2015)). At the other end of the spectrum, some market participants argue that, in spite of the fact that SEFs are open to all market participants by law,[20] there are market practices that prevent clients from using IDB SEFs (see, e.g., Managed Funds Association (2015)). One such practice is post-trade name give-up whereby anonymously matched traders learn about the identity of their counterparty after the trade is executed. This risk of uncontrolled information leakage makes IDB SEFs unattractive to many clients; in particular, those that use proprietary trading strategies.[21]

will facilitate trading among market participants directly without having to route all trades through dealers." See 78 Federal Register at 33565 (Jun. 4, 2013).

[20] The requirements that market participants have to meet in order to get access to a SEF must be rules-based and applied in a non-discriminatory manner for all market participants (see §37.202 of Chapter I of 17 CFR).

[21] Trading via RFQ also entails a certain amount of information leakage, but in this case the client has control over which dealers receive the information. Because the vast majority of index CDSs are centrally cleared, there is no reason for post-trade name give-up from a counterparty risk perspective. However, some dealers argue that name give-up is needed to prevent predatory trading by clients (see, e.g., "How to Game a SEF: Banks Fear Arrival of Arbitrageurs," *Risk Magazine*, March 19, 2014).

3 Data and Identification Algorithms

This section describes the transaction and quote data and the algorithms that identify SEFs and package transactions.

3.1 Transaction Data

Our empirical analysis is based on transaction data over a two-year period from October 2, 2013 to October 16, 2015. The data come from the three SDRs that disseminate trade reports of index CDS transactions: the Bloomberg Swap Data Repository (BSDR), the Depository Trust & Clearing Corporation Data Repository (DDR), and the Intercontinental Exchange Trade Vault (ICETV). Trade reports contain execution timestamps, transaction prices, and trade sizes up to a cap of at least USD 100 million,[22] and they indicate whether the trade is centrally cleared, whether it features non-standard (or bespoke) contract terms, and whether it is subject to an end-user exception that exempts the trade from the clearing and trade execution requirements.[23] The trade reports also indicate whether the trade is executed on a SEF, but they do not specify which one. They also do not specify whether the trade is part of a package; i.e., a transaction that involves more than one index CDS or an index CDS and another instrument, such as an index swaption or tranche swap (both of which are conventionally traded with delta, see below).[24] Fortunately, SEFs and package transactions can be identified from trade reports once the transaction data are limited to trades that are executed on SEFs.

It should be emphasized that limiting the sample to trades that are executed on SEFs is

[22] The actual cap size is the larger of USD 100 million and the minimum block size (see §43.4(h) of Chapter I of 17 CFR).

[23] This would be the case if one counterparty is a non-financial entity that uses the trade to hedge commercial risks (see Sections 2(h)(7) and 2(h)(8) of the CEA).

[24] There are other important trade characteristics that are not specified in the trade reports. For instance, trade reports do not specify whether the trade is buyer- or seller-initiated, whether it is D2C or D2D, and whether it is executed via an order book or RFQ functionality.

not restrictive because we focus on trades in the most actively traded five-year on-the-run index CDSs. After February 26, 2014 trades in these index CDSs are required to be executed on SEFs. In the initial period from October 2, 2013 to February 25, 2014, on-SEF trade execution was non-mandatory for these index CDSs but the majority of trades were executed on SEFs (the Internet Appendix contains additional details).

3.2 Identification of SEFs

In devising the SEF identification algorithm, we use SEF-reported trading volumes from Clarus FT.[25] Each of the on-SEF trade reports must have been submitted by one of the eight aforementioned SEFs. Bloomberg SEF submits trade reports to the BSDR and ICE Swap Trade submits trade reports to the ICETV. The remaining SEFs submit trade reports to the DDR and the trade-report-submitting SEF can be identified based on the format of the trade report. Specifically, we associate with each SEF the format of trade reports whose aggregate trade size corresponds to the SEF-reported trading volume over our sample period (the Internet Appendix contains the details). The SEF on which a trade is executed reveals whether the trade is D2C or D2D.

3.3 Identification of Package Transactions

We identify four popular types of package transactions: index rolls, curve trades, delta-hedged index swaptions, and delta-hedged index tranche swaps (the Internet Appendix contains the details). A typical index roll involves an on-the-run and an off-the-run index CDS with the same contract tenor. Protection is sold on one index series and simultaneously bought on the other. Index rolls are popular because many institutional investors like to maintain liquid credit exposure with a relatively constant maturity profile. We identify in-

[25] Clarus FT is the standard data source for SEF-reported daily trading volumes. In the Internet Appendix, we describe the Clarus FT data in detail.

dex rolls as simultaneously executed index CDS trades on the same SEF that have the same contract tenor and reference two different series of the same index.

A typical curve trade involves two index CDSs with different contract tenors.[26] Protection is sold on one contract tenor and simultaneously bought on the other. Curve trades are popular because they are relatively directional (index CDS term structures tend to become flatter when spreads widen and steeper when spreads contract; see, e.g., Erlandsson, Ghosh, and Rennison (2008)) and require less capital outlay than outright index CDS trades. We identify curve trades as simultaneously executed index CDS trades on the same SEF that have different contract tenors and reference the same index (but not necessarily the same index series).

We also account for the fact that index swaptions and tranche swaps are conventionally traded "with delta;" i.e., together with a delta hedge in the corresponding index CDS. Quotes of index swaptions and tranche swaps incorporate both the delta and the so-called "reference level" at which the delta hedge will be traded. Usually, the reference level is set close to the par spread at which the index CDS trades at the beginning of the trading day (see, e.g., Hünseler (2013)), but it might be updated throughout the trading day because of spread movements. For CDX.IG, the reference level is usually set in spread multiples of 0.5 bps.[27] We identify index swaption and tranche swap delta hedges as index CDS trades that have the same underlying index and contract tenor as an index swaption or tranche swap trade. Trade executions must be near simultaneous and notional amounts must be reconcilable with a delta that is quoted on the same trading day.

Index swaptions and tranche swaps can also be traded without delta but usually at less favorable prices that incorporate the dealer's cost of establishing the hedge. Therefore, investors may find it beneficial to trade index swaptions and tranche swaps with delta and

[26] Typically, the two index CDSs reference the same index series, but there are also curve trades in which the two index CDSs reference different index series.

[27] Because CDX.HY is quoted in terms of a price, the reference level is usually set in price multiples of 0.125%.

unwind the hedge themselves (see, e.g., Hünseler (2013)). We identify such delta unwinds as trades with the same transaction price and notional amount as a delta hedge of an index swaption or tranche swap trade that occurs on the same trading day and SEF.

3.4 Descriptive Statistics of On-SEF Trades

Table 1 displays descriptive statistics of the enriched transaction data that allows to distinguish between D2C and D2D trades and between outright trades and package transactions. Descriptive statistics are computed separately for D2C and D2D trades in CDX.IG (Panels A1 and A2, respectively) and CDX.HY (Panels B1 and B2, respectively) and, within these broad categories of trades, descriptive statistics are computed separately for trades that are executed on a given SEF.

[Table 1 about here.]

The index CDS market is characterized by relatively few trades in very large sizes. For CDX.IG, there are 114 D2C trades and 24 D2D trades per day, on average, and the median trade size is USD 50 million in both segments. For CDX.HY, there are somewhat more trades (164 D2C trades and 27 D2D trades per day, on average), but the median trade size is smaller (USD 10 million in both segments) because of the significantly higher volatility of high-yield contracts, see below.

Trading volumes are large. The average daily D2C trading volumes are USD 9.843 billion for CDX.IG and USD 3.705 billion for CDX.HY. The corresponding D2D trading volumes are USD 1.354 billion and USD 0.402 billion.[28] These averages appear in parenthesis in the table because they are based on SEF-reported daily trading volumes from Clarus FT

[28] D2D trading accounts for 10% (for CDX.HY) to 12% (for CDX.IG) of total volume in the index CDS market. The International Swaps and Derivatives Association (2014, ISDA) estimates that, in the case of interest rate swaps, D2D trading accounts for 35% of total volume. However, the ISDA (2014) argues that as much as two-thirds of D2D trading is due to non-price-forming trades, such as amendments, novations, and terminations, all of which are excluded from our sample. This brings the ISDA's (2014) estimate for interest rate swaps more in line with the one we find for index CDSs in our sample.

instead of transaction data. They cannot be reproduced with transaction data because trade reports contain capped trade sizes. Indeed, the table shows that the fractions of D2C (D2D) trades that are disseminated with capped notional amounts are 21.2% (6.8%) for CDX.IG and 2.3% (1.4%) for CDX.HY.[29] As a consequence, transaction-data-based average daily trading volumes are downward biased.[30]

The vast majority of trades are in the five-year contract tenor and around 90% of trades are in on-the-run index CDSs. Almost all trades have standardized contract terms and are centrally cleared.[31] The fact that there are virtually no D2D block trades, whereas about 20% of D2C trades are blocks, is consistent with the use of order book functionalities on IDB SEFs. This is because block-sized trades that are executed via an order book functionality do not qualify as block trades. Outright trades account for most of the trading volume and among package transactions, index rolls are most popular.

We focus on analyzing transaction costs of outright trades in five-year on-the-run index CDSs. These trades account for 88.5% and 84.6% of D2C trading volume in CDX.IG and CDX.HY, respectively, and 67.2% and 63.5% of D2D trading volume. For all other trade types there are either too few trades or too few quotes to reliably measure transaction costs

[29] In comparison to trades in CDX.IG, the percentage of trades that are disseminated with capped notional amounts is lower for trades in CDX.HY because the latter tend to be of smaller size (in absolute terms and relative to the cap). The median size of trades in CDX.IG is five times that of trades in CDX.HY, but caps typically differ by USD 10 million only (for trades in CDX.IG the cap is typically USD 110 million and for trades in CDX.HY the cap is typically USD 100 million).

[30] The actual volumes allow to impute by how much the size of trades that are disseminated with capped notional amounts exceeds the cap on average. For instance, the size of D2C trades in CDX.IG that are disseminated with capped notional amounts exceeds the cap by USD 141.13 ($= 511 \times (9,843 - 6,434)/(0.212 \times 58,224)$) million, on average (511 is the number of trading days in the sample period). Most of these trades are capped at USD 110 million, suggesting that, conditional on being capped, the average size of D2C trades in CDX.IG is approximately USD 250 million. Similarly, conditional on being capped, the average size of D2D trades in CDX.IG is approximately USD 200 million. For CDX.HY, most trades are capped at USD 100 million and conditional on being capped, the average sizes of D2C and D2D trades in CDX.HY are approximately USD 225 million and USD 160 million, respectively.

[31] Loon and Zhong (2016) find that bespoke contract terms, central clearing, and a counterparty that qualifies as an end-user are trade characteristics that significantly affect transaction costs of index CDSs. These characteristics cannot be a main driver of potential transaction cost differences between D2C and D2D trades because the vast majority of both D2C and D2D trades are non-bespoke and centrally cleared, and there are few end-user exempt trades in our sample (there are no such trades after February 10, 2014).

at the trade level and across market segments.

3.5 Quote Data

The quote data come from Markit and GFI. Markit intraday composite quotes constitute the main real-time reference in the index CDS market that is available to all market participants. The composite bid and offer quotes average over indicative quotes that dealers provide to their institutional clients. Indicative quoting by dealers is standard market practice and takes place throughout the trading day via electronic messaging.[32] Markit parses the client quotes of individual dealers from their messages and updates the composites whenever a dealer sends out a message.[33]

GFI inside quotes represent executable prices in the interdealer market. The inside bid and offer quotes are the best prices at which protection can be sold or bought on the limit order book of the GFI SEF. Virtually all dealers are active on the GFI SEF as it is the main IDB SEF in terms of both trades and trading volume (see Table 1).

Figure 1 displays daily averages of mid-quotes. For both indices, daily averages of the two mid-quotes are visually indistinguishable because the spreads at which the index CDSs trade in the two segments of the market ultimately reflect the credit risk of the same index constituents. CDX.HY is more volatile than CDX.IG, with the standard deviation of daily changes being 1.46 bps for CDX.IG and 7.95 bps for CDX.HY.

[Figure 1 about here.]

On average, there are 448 and 396 Markit quotes per day for CDX.IG and CDX.HY, respectively, and 1,094 and 864 GFI quotes. Quoting is continuous during New York trading

[32] The actual messages are called "dealer runs." Messages are send out to the entire client base of a dealer's credit derivatives trading desk and they typically contain quotes for several index CDSs and other credit derivatives. Clients can expect to buy and sell in standard size at prices close to the indicative quotes.

[33] The quotes from each dealer's latest message are used for the computation of composites provided that the message is no older than 15 minutes. Moreover, a five-minute memory prevents repeated computations of the same composite.

hours, with 97% of Markit quotes and almost all GFI quotes being made between 7:00 a.m. and 5:00 p.m. New York time. During this part of the day, Markit quotes are updated, on average, every 79 seconds for CDX.IG and every 89 seconds for CDX.HY. GFI quotes for CDX.IG and CDX.HY are updated every 29 and 37 seconds, respectively.

Figure 2 shows transaction prices and mid-quotes on a representative trading day, May 6, 2015, for the five-year index CDS contract on the then on-the-run series of CDX.IG. There are 165 trades, 405 Markit quotes, and 739 GFI quotes. The two mid-quotes move in lockstep during the trading day. The few deviations that occur are small and temporary.

[Figure 2 about here.]

Most striking are the trades at 64 bps and 66 bps that appear to be outliers in comparison to the other trades that tend to be relatively close to both mid-quotes. These trades are classified as delta hedges of index swaption trades by our identification algorithm for package transactions. The transaction prices on the index CDS legs of package transactions generally do not reflect the par spread at which outright trades are executed because packages are either quoted in relative terms (index rolls and curve trades) or along with a non-price-forming quote for the delta hedge (delta-hedged index swaptions and tranche swaps). It is because of this difference in the pricing of outright trades and package transactions that it is important to take into account whether or not a trade is part of a package.

4 Transaction Costs

We now compare transaction costs and price impacts across D2C and D2D trades. We also control for differences in trade characteristics and market conditions under which trades are executed.

4.1 Transaction Cost Decomposition

We measure the cost of a transaction by the effective half-spread with respect to the mid-quote in the relevant market segment. For a D2C trade, the effective half-spread is with respect to the Markit mid-quote and for a D2D trade, it is with respect to the GFI mid-quote. We further decompose the effective half-spread into a price impact and a realized half-spread, which measures the cost of a transaction after taking price impact into account. Specifically, let τ indicate whether the trade is D2C or D2D; then

$$\underbrace{q_t(p_t - m_t^\tau)}_{=\text{EffcSprd}_t} = \underbrace{q_t(p_t - m_{t+\Delta}^\tau)}_{=\text{RlzdSprd}_t} + \underbrace{q_t(m_{t+\Delta}^\tau - m_t^\tau)}_{=\text{PrcImp}_t}, \quad \tau \in \{\text{D2C}, \text{D2D}\}, \tag{1}$$

where p_t is the transaction price, m_t^{D2C} and m_t^{D2D} are the latest Markit and GFI mid-quotes, respectively, in the 15-minute period prior to trade execution, and $m_{t+\Delta}^{\text{D2C}}$ and $m_{t+\Delta}^{\text{D2D}}$ are the respective mid-quotes that prevail 15 minutes after trade execution. Trade direction, q_t, is inferred by the Lee and Ready (1991) algorithm and equals $+1$ (-1) in the case of protection-buyer-initiated (protection-seller-initiated) trades.[34]

Measuring price impact by trade-induced mid-quote changes is standard in empirical market microstructure, but the definition becomes ambiguous when there is no consolidated quote. Ultimately, all quotes should be driven by a common efficient price, with potential differences in the measurement of price impact being due to temporary deviations between mid-quotes. The cointegrated VAR model that we estimate in Section 5 filters out the temporary deviations by taking into account the dynamic interactions between trades and mid-quotes across the two market segments.

[34] Following Lee and Ready (1991), we sign trades at the mid-quote by a tick test. For a D2C trade, the tick test is applied to the sequence of D2C trades and for a D2D trade, it is applied to the sequence of D2D trades.

4.2 Transaction Costs Across Market Segments

Figure 3 shows daily averages of effective half-spreads for D2C and D2D trades. For both indices, D2C trades have consistently higher effective half-spreads than D2D trades. The overall level of transaction costs is low relative to the par spreads at which the index CDSs trade (see Figure 1).

[Figure 3 about here.]

Table 2 displays average effective half-spreads, realized half-spreads, and price impacts by market segment. The results confirm the impression from Figure 3. For CDX.IG, average effective half-spreads for D2C and D2D trades are 0.138 bps and 0.098 bps, respectively, with the difference of 0.040 bps being statistically significant. The corresponding figures for CDX.HY are 0.676 bps and 0.494 bps, with the difference of 0.181 bps again being statistically significant.

[Table 2 about here.]

These transaction cost differentials are due to D2C trades having higher price impact than D2D trades. For CDX.IG, average price impacts for D2C and D2D trades are 0.102 bps and 0.060 bps, respectively, with the difference of 0.042 bps being statistically significant. The corresponding figures for CDX.HY are 0.492 bps and 0.247 bps, with the difference of 0.246 bps again being statistically significant. After taking price impact into account, D2C trades have lower transaction costs (as captured by realized half-spreads) than D2D trades.

Table 2 also displays averages by quartiles of the trade size distribution, showing that, for all trade sizes, effective half-spreads and price impacts of D2C trades are significantly higher than those of D2D trades. Furthermore, for both indices, effective half-spreads of D2C trades increase with trade size which is in contrast to evidence from other dealer markets, such as the corporate and municipal bond markets, where transaction costs typically decrease with trade

size; see, e.g., Bessembinder, Maxwell, and Venkataraman (2006), Edwards et al. (2007), Goldstein et al. (2007), Harris and Piwowar (2006), and Green, Hollifield, and Schürhoff (2007). This likely reflects structural differences between markets: the index CDS market is purely institutional with professional investors trading in large sizes; in contrast, there is significant retail participation in bond markets with relatively unsophisticated market participants trading in small sizes and with dealers who can exert market power.[35]

For both indices, price impact of D2C trades tends to increase with trade size as well but only up to the third quartile of the trade size distribution. The lower price impact of block-sized trades in the fourth quartile of the trade size distribution is consistent with block trade provisions that aim at mitigating the price impact of block-sized trades.

4.3 Controlling for Trade Characteristics and Market Conditions

Potential explanations for differences in average effective half-spreads and price impacts of D2C and D2D trades are that trade characteristics are different or that trades are executed under different market conditions. For this reason, we regress separately the effective half-spread, the realized half-spread, or the price impact of a trade on trade-size dummies, their interactions with the negative of a D2D dummy (negation is for comparability with Table 2), an additional trade characteristic, and control variables for the market conditions that prevail at trade execution.

The additional trade characteristic is a dummy variable for trades with transaction prices at which reference levels of index swaption and tranche swap trades tend to be set. The

[35] More generally, Bjønnes et al. (2016) argue that the effective half-spread in OTC markets includes a price discrimination component and an informational component. Transaction costs decrease with trade size when the price discrimination component outweighs the informational component, and vice versa. Bjønnes et al. (2016) also note that the informational component may itself be negatively correlated with the effective half-spread when post-trade transparency is low and when trading in the interdealer market is sufficiently active which is not the case for the post-Dodd-Frank index CDS market. Moreover, index CDS dealers' ability to price discriminate is limited by direct competition in multi-dealer RFQs, which may explain why Loon and Zhong (2016) find that transaction costs of index CDS decrease with trade size in a sample that predates the trade execution requirement of the Dodd-Frank Act.

dummy accounts for potentially unidentified delta hedges.[36] The control variables for market conditions include the bid-offer spreads of the latest Markit and GFI quotes, the end-of-day composite par spread, and the end-of-day implied volatility of the at-the-money three-month option on the index CDS. The control variables are stated in deviations from their sample means for comparability with Table 2.

Table 3 displays regression results. The variables of interest are the interactions with the negative of the D2D dummy, which are the regression-implied equivalents of the differences in Table 2. Controlling for trade characteristics and market conditions reduces the differences in effective half-spreads and price impacts of D2C and D2D trades. However, the conclusions from Table 2 do not materially change; differences in price impact fully explain the differences in transaction costs.

[Table 3 about here.]

For both indices, the estimated regression coefficients show that transaction costs increase with trade size, bid-offer spreads, and implied volatility. In addition, trades with reference level transaction prices are more expensive. Price impacts increase with bid-offer spreads and implied volatility. The GFI bid-offer spread has no incremental effect on price impact. This suggests that the informational components of the Markit and GFI bid-offer spreads are largely the same which is consistent with information asymmetries among dealers that originate from informed client trades. Price impacts tend to increase with trade size; however, block-sized trades have lower price impacts than large-sized trades in the third quartile of the trade size distribution.

The Internet Appendix shows that our results are robust to using an alternative client mid-quote from Credit Market Analysis, restricting the sample to the period when trading

[36] One reason for unidentified delta hedges is that we only identify delta hedges of on-SEF index swaption and tranche swap trades, but neither swaptions nor tranche swaps have to be traded on SEFs. Nevertheless, the delta hedges of off-SEF index swaption and tranche swap trades would typically be executed on SEFs in order to satisfy other regulatory requirements.

on SEFs is mandatory, and computing price impacts and realized half-spreads over longer periods of time.

5 The Dynamics of Trades and Quotes

We now consider a cointegrated VAR model in the spirit of Hasbrouck (1995), which provides a robust and flexible tool to study the dynamic interactions between trades and quotes in cases where more than one quote is relevant to the analysis. The model also allows to measure the information content of D2C and D2D trades and to quantify their relative importance for price discovery.

5.1 Cointegrated VAR Model and Estimation

We estimate the error correction form of the cointegrated VAR model in event time, with t indexing the t-th revision of client quotes.[37] Specifically,

$$\Delta m_t^{\mathrm{D2C}} = \lambda_1 z_{t-1} + \sum_{j=1}^{20} \alpha_j \Delta m_{t-j}^{\mathrm{D2C}} + \sum_{j=0}^{20} \beta_j \Delta m_{t-j}^{\mathrm{D2D}} + \sum_{j=0}^{20} \gamma_j x_{t-j}^{\mathrm{D2C}} + \sum_{j=0}^{20} \delta_j x_{t-j}^{\mathrm{D2D}} + \epsilon_{m,t}^{\mathrm{D2C}}, \quad \text{(2a)}$$

$$\Delta m_t^{\mathrm{D2D}} = \lambda_2 z_{t-1} + \sum_{j=1}^{20} \zeta_j \Delta m_{t-j}^{\mathrm{D2C}} + \sum_{j=1}^{20} \eta_j \Delta m_{t-j}^{\mathrm{D2D}} + \sum_{j=0}^{20} \theta_j x_{t-j}^{\mathrm{D2C}} + \sum_{j=0}^{20} \kappa_j x_{t-j}^{\mathrm{D2D}} + \epsilon_{m,t}^{\mathrm{D2D}}, \quad \text{(2b)}$$

$$x_t^{\mathrm{D2C}} = \lambda_3 z_{t-1} + \sum_{j=1}^{20} \nu_j \Delta m_{t-j}^{\mathrm{D2C}} + \sum_{j=1}^{20} \xi_j \Delta m_{t-j}^{\mathrm{D2D}} + \sum_{j=1}^{20} \pi_j x_{t-j}^{\mathrm{D2C}} + \sum_{j=1}^{20} \rho_j x_{t-j}^{\mathrm{D2D}} + \epsilon_{x,t}^{\mathrm{D2C}}, \quad \text{(2c)}$$

$$x_t^{\mathrm{D2D}} = \lambda_4 z_{t-1} + \sum_{j=1}^{20} \phi_j \Delta m_{t-j}^{\mathrm{D2C}} + \sum_{j=1}^{20} \chi_j \Delta m_{t-j}^{\mathrm{D2D}} + \sum_{j=0}^{20} \psi_j x_{t-j}^{\mathrm{D2C}} + \sum_{j=1}^{20} \omega_j x_{t-j}^{\mathrm{D2D}} + \epsilon_{x,t}^{\mathrm{D2D}}, \quad \text{(2d)}$$

where the first term on the right hand side of each equation is the error correction term, $z_t = m_t^{\mathrm{D2C}} - m_t^{\mathrm{D2D}}$ is the cointegrating relation, and x_t^{D2C} and x_t^{D2D} are D2C- and D2D-trade-related variables, respectively, which count the number of signed D2C and D2D trades

[37] In the sequel, the error correction form will be referred to as vector error correction model (VECM).

that occur between the $t-1$-th and t-th revision of client quotes (i.e., x_t^{D2C} and x_t^{D2D} are sums of the above trade direction indicators, q_u, with u between the calendar time of the $t-1$-th and t-th revision of client quotes). The error terms, $\epsilon_{m,t}^{\text{D2C}}$, $\epsilon_{m,t}^{\text{D2D}}$, $\epsilon_{x,t}^{\text{D2C}}$, and $\epsilon_{x,t}^{\text{D2D}}$, are uncorrelated because we resolve contemporaneous effects by including contemporaneous variables in Equations (2a), (2b), and (2d).[38] Intuitively, the D2C-trade-related variable may contemporaneously affect the D2D-trade-related variable when dealers immediately offload inventory in the interdealer market. The D2D-trade-related variable may contemporaneously affect the GFI mid-quote directly when a trade in the limit order book of the GFI SEF depletes depth at the inside quote or indirectly when dealers immediately adjust their limit orders in response to D2D trades. Adjustment of limit orders is also how the D2C-trade-related variable may contemporaneously affect the GFI mid-quote. Finally, the D2C- and D2D-trade-related variables may contemporaneously affect the Markit mid-quote when dealers immediately revise client quotes in response to trades, and the GFI mid-quote may contemporaneously affect the Markit mid-quote when dealers set client quotes relative to the mid-quote in the interdealer market.

Cointegration in the present framework captures the idea that supply and demand imbalances in the two segments of the market may lead to temporary deviations between mid-quotes, but there is an unobservable efficient price, m_t, which is common to both market segments, that ultimately drives mid-quotes. This is clearly seen from the vector moving average (VMA) or Granger representation of the cointergrated VAR model. In our case, it

[38] Moreover, error terms are assumed to be serially uncorrelated and homoscedastic.

is given by

$$m_t^{\text{D2C}} = m_t \ + a(L)\epsilon_{m,t}^{\text{D2C}} + b(L)\epsilon_{m,t}^{\text{D2D}} \ + c(L)\epsilon_{x,t}^{\text{D2C}} \ + d(L)\epsilon_{x,t}^{\text{D2D}}, \tag{3a}$$

$$m_t^{\text{D2D}} = m_t \ + e(L)\epsilon_{m,t}^{\text{D2C}} \ + f(L)\epsilon_{m,t}^{\text{D2D}} + g(L)\epsilon_{x,t}^{\text{D2C}} + h(L)\epsilon_{x,t}^{\text{D2D}}, \tag{3b}$$

$$n_t^{\text{D2C}} = y_{2,t} + k(L)\epsilon_{m,t}^{\text{D2C}} + l(L)\epsilon_{m,t}^{\text{D2D}} \ + p(L)\epsilon_{x,t}^{\text{D2C}} + q(L)\epsilon_{x,t}^{\text{D2D}}, \tag{3c}$$

$$n_t^{\text{D2D}} = y_{3,t} + r(L)\epsilon_{m,t}^{\text{D2C}} \ + u(L)\epsilon_{m,t}^{\text{D2D}} + v(L)\epsilon_{x,t}^{\text{D2C}} + w(L)\epsilon_{x,t}^{\text{D2D}}, \tag{3d}$$

where $n_t^\tau = \sum_{s=1}^t x_s^\tau$, $\tau \in \{\text{D2C},\ \text{D2D}\}$, is the aggregate number of signed τ trades between the first and t-th revision of client quotes, $a(L),\ b(L),\ \ldots,\ w(L)$ are polynomial lag operators whose coefficients $a_j,\ b_j,\ \ldots,\ w_j,\ j = 0, 1, \ldots,$ converge to zero for $j \to \infty$, and $y_t = (m_t,\ y_{2,t},\ y_{3t})'$ is a three dimensional random walk with initial value $y_0 = ((m_0^{\text{D2C}} + m_0^{\text{D2D}})/2,\ 0,\ 0)'$ and innovation $\Delta y_t = \Psi\epsilon_t$. The 3×4 matrix Ψ plays an important role in characterizing price impact and studying the role of trades in the price discovery process, and it is explicitly given in terms of VECM parameters.[39]

In the spirit of Hasbrouck (1991a), we measure the information content of D2C and D2D trades by the permanent price impact of shocks to the trade-related variables. It immediately follows from Equation (3a), that the impact of a single protection-buyer-initiated D2C trade on the Markit mid-quote is

$$\sum_{j=0}^{n} \mathbb{E}\big[\Delta m_{t+j}^{\text{D2C}} \big| \text{D2C}_t\big] = \mathbb{E}\big[m_{t+n}^{\text{D2C}} \big| \text{D2C}_t\big] - m_{t-1}^{\text{D2C}} = \Psi_{13} + c_n \tag{4}$$

after $n+1$ revisions of client quotes, where $\text{D2C}_t = \big\{\epsilon_{x,t}^{\text{D2C}} = 1,\ \epsilon_{m,t}^{\text{D2C}} = \epsilon_{m,t}^{\text{D2D}} = \epsilon_{x,t}^{\text{D2D}} = 0,\ \epsilon_{m,s}^{\text{D2C}} = \epsilon_{m,s}^{\text{D2D}} = \epsilon_{x,s}^{\text{D2C}} = \epsilon_{x,s}^{\text{D2D}} = 0,\ s < t\big\}$ denotes the event of an isolated unit-sized shock

[39] Specifically, let $\tilde{\beta}$ be the cointegration vector satisfying $z_t = (m_t^{\text{D2C}},\ m_t^{\text{D2D}},\ n_t^{\text{D2C}},\ n_t^{\text{D2D}})\tilde{\beta}$ and let $\lambda = (\lambda_1,\ \lambda_2,\ \lambda_3,\ \lambda_4)'$. Then, $\Psi = (\lambda_\perp'\Gamma\tilde{\beta}_\perp)^{-1}\lambda_\perp'$, where $\lambda_\perp$ and $\tilde{\beta}_\perp$ span the null spaces of λ' and $\tilde{\beta}'$, respectively, and $\Gamma = I - \sum_{j=0}^{20}\Gamma_j$, with I being the identity matrix and Γ_j being the autoregressive coefficient matrices of the VECM.

of the D2C-trade-related variable.[40] Similarly, it follows from Equation (3b), that the impact of the trade on the GFI mid-quote is

$$\sum_{j=0}^{n} \mathbb{E}\big[\Delta m_{t+j}^{\mathrm{D2D}} \big| \mathrm{D2C}_t\big] = \mathbb{E}\big[m_{t+n}^{\mathrm{D2D}} \big| \mathrm{D2C}_t\big] - m_{t-1}^{\mathrm{D2D}} = \Psi_{13} + g_n \tag{5}$$

after $n+1$ revisions of client quotes. Consequently, the trade has the same permanent price impact on both quotes, which is given by

$$\Psi_{\mathrm{D2C}} = \lim_{n\to\infty} \sum_{j=0}^{n} \mathbb{E}\big[\Delta m_{t+j}^{\mathrm{D2C}} \big| \mathrm{D2C}_t\big] = \lim_{n\to\infty} \sum_{j=0}^{n} \mathbb{E}\big[\Delta m_{t+j}^{\mathrm{D2D}} \big| \mathrm{D2C}_t\big] = \Psi_{13}. \tag{6}$$

Similarly, the permanent price impact of a single protection-buyer-initiated D2D trade is $\Psi_{\mathrm{D2D}} = \Psi_{14}$.

The above is based on the more general idea that efficient price innovations—which are permanently incorporated into prices—reflect information. Hasbrouck (1991b) shows that the variance of efficient price innovations, $\sigma^2_{\Delta m}$, can be explicitly expressed in terms of error term variances and VECM parameters. Specifically,

$$\sigma^2_{\Delta m} = \underbrace{(\Psi_{11})^2 \sigma^2_{m,\mathrm{D2C}} + (\Psi_{12})^2 \sigma^2_{m,\mathrm{D2D}}}_{\text{trade-unrelated}} + \underbrace{(\Psi_{13})^2 \sigma^2_{x,\mathrm{D2C}}}_{\text{D2C-trade-related}} + \underbrace{(\Psi_{14})^2 \sigma^2_{x,\mathrm{D2D}}}_{\text{D2D-trade-related}}, \tag{7}$$

where $\sigma^2_{m,\tau} = \mathbb{V}\big(\epsilon^{\tau}_{m,t}\big)$ and $\sigma^2_{x,\tau} = \mathbb{V}\big(\epsilon^{\tau}_{x,t}\big)$, $\tau \in \{\mathrm{D2C},\ \mathrm{D2D}\}$. Equation (7) reflects a decomposition of efficient price innovations into three mutually orthogonal components: a trade-unrelated component with variance given by the sum of the first two terms on the right hand side of Equation (7), and two trade-related components with variances given by the third and fourth term. The first trade-related component is associated with D2C trades and the second

[40] A single protection-buyer-initiated D2C trade is an event in $\mathrm{D2C}_t$ but obviously not the only event that gives rise to a unit-sized shock of the D2C-trade-related variable. For instance, occurrence of two protection-buyer-initiated D2C trades and one protection-seller-initiated D2C trade between the $t-1$-th and t-th revision of client quotes also result in a unit-sized shock of the D2C-trade-related variable.

one is associated with D2D trades. Equation (7) is the basis for measuring contributions to price discovery by Hasbrouck's (1991b) R^2, which expresses each component's variance as a fraction of $\sigma^2_{\Delta m}$. The trade-unrelated component is not further broken down into Hasbrouck's (1995) information shares because informational attribution to market segments is elusive when the same dealers set prices in both segments of the market.

We estimate the VECM using all revisions of client quotes (as captured by updates of Markit intraday composite quotes) between 7:00 a.m. and 5:00 p.m. New York time for which both mid-quotes are available at the beginning of the time period that spans the quote revision. We exclude a few intraday periods during which Markit quotes are stale.[41] Finally, we winsorize mid-quote changes at the 0.1% and 99.9% quantile of their distribution.

5.2 Results

Panels A1 and A2 of Table 4 display VECM coefficient estimates for CDX.IG and CDX.HY, respectively. The results are similar for both indices and, therefore, our discussion focuses on CDX.IG. First, consider the adjustment coefficients. Both mid-quotes adjust against deviations from the long-run equilibrium relationship. Moreover, the significant adjustment coefficients in Equations (2c) and (2d) suggests that there is also trading against those deviations, with D2C and D2D trades occurring in opposite directions. D2C trades tend to be protection seller initiated when the Markit mid-quote is high relative to the GFI mid-quote and vice versa, when the Markit mid-quote is relatively low.

[Table 4 about here.]

Next, consider how trades affect mid-quotes. The positive and significant coefficients on the contemporaneous trade-related variables in Equations (2a) and (2b) show that dealers, on average, immediately raise quotes in response to protection-buyer-initiated trades. For both

[41] During these periods there are typically neither quotes for CDX.IG nor for CDX.HY, suggesting technical disruptions to Markit's quote generating process.

mid-quotes, the immediate price impact of D2C trades is higher than that of D2D trades. The coefficients on the lagged trade-related variables are generally positive (for brevity the table only reports sums of autoregressive coefficients and the corresponding t-statistics) indicating that mid-quotes are raised further in subsequent revisions.

Finally, consider the dynamics of trades. The generally positive coefficients on the lagged D2C-trade-related (D2D-trade-related) variables in Equation (2c) (Equation (2d)) indicate positively autocorrelated trades, a pervasive feature in financial markets.[42] More interestingly, the coefficients on the lagged D2C-trade-related variable in Equation (2d) are generally positive. Furthermore, bivariate Granger causality tests show that D2C- and D2D-trade-related variables are characterized by one-way Granger causality from D2C trades to D2D trades (these results are reported in the Internet Appendix). This is consistent with inventory management taking place in the interdealer market.[43]

Figure 4 displays the model-implied price impacts of D2C and D2D trades. Specifically, Panels A and C trace out how the Markit mid-quote changes following a single protection-buyer-initiated D2C or D2D trade, and Panels B and D trace out how the GFI mid-quote changes. Price impact unfolds in a distinct manner across mid-quotes but ultimately converges to the same permanent price impact. The price impact is higher for D2C trades and largely permanent. Panel B of Table 4 displays the permanent price impact of a trade and formally rejects the hypothesis of identical permanent price impacts of D2C and D2D trades.

[Figure 4 about here.]

Asymmetric information entails a permanent price impact, while inventory control entails a transient price impact. We observe a small transient component in the change of the

[42] Positive autocorrelation of trades could, for instance, stem from order splitting or correlation in trading strategies across agents. In comparison to anonymous limit-order-book markets, there is less of a rationale for order splitting in OTC markets (at least for D2C trades, which are typically not executed anonymously).

[43] In addition, dealers have told us that CDX positions are often hedged using other liquid instruments, such as S&P 500 futures.

Markit mid-quote in response to a D2C trade, consistent with the quote revision mechanism in standard inventory control models. However, the overall quote revision is dominated by the permanent price impact, which points to clients trading on information. This could, for instance, be private information about the credit risk of certain index constituents (see, e.g., Acharya and Johnson (2007) and Ivashina and Sun (2011)) or stem from an advantage over dealers in interpreting public information in relation to the aggregate credit risk in the economy. The lower permanent price impact of D2D trades is consistent with dealers mainly using the interdealer market for inventory management. From this it also follows that D2C trades play a more important role in the price discovery process than D2D trades. Indeed, Panel C of Table 4 shows that D2C trades account for a much greater proportion of the efficient price variance than D2D trades.

The Internet Appendix shows that our results are robust to using an alternative client mid-quote, restricting the sample to the period when trading on SEFs is mandatory, taking the size of trades into account, and estimating the cointegrated VAR model in calendar time.

6 Trading Protocols

While trading in the D2C segment is almost exclusively via RFQ, a number of different trading protocols are used in the interdealer market besides the limit order book. Of particular interest are size-discovery trading protocols in which size orders are matched at a known fixed price (see, e.g., Duffie and Zhu (2017)). We collect additional data from the GFI SEF to investigate how transaction costs and price impacts vary across trading protocols on this SEF.[44]

[44]Focusing on trades that are executed on the GFI SEF is not restrictive because it is the main IDB SEF. Other IDB SEFs also offer size-discovery trading mechanisms, but the data are not readily available.

6.1 Size-Discovery Trading Protocols

The GFI SEF offers two size-discovery trading protocols—mid-market matching and workup—in addition to a standard limit order book and an RFQ trading protocol (both of which are price-discovery trading protocols). For five-year on-the-run index CDSs, the predominant matching protocol is continuous mid-market matching.[45] At any point in time, market participants can submit size orders for matching at a "mid-market level" and any opposing interests immediately result in a trade. The mid-market level is fixed by a GFI broker and it is usually somewhere between the inside quotes on the limit order book but not necessarily equal to the mid-quote. The mid-market level is displayed on the trading screen that shows the limit order book, and the color in which the mid-market level is displayed indicates whether or not there is interest for matching. The direction and size of interests are not displayed, but market participants know that interests must be at least of a minimum size.[46]

A workup session on the GFI SEF is initiated by a trade in the limit order book. During the session, the parties to the initiating trade and other market participants joining the trade can work up the size of the trade by submitting size orders that, in case of a match, result in trades at the transaction price of the initiating trade. The aggressor and liquidity provider of the initiating trade are privileged by means of a 10-second exclusivity period during which they are the only market participants who can work up trade size. The exclusivity period is followed by a public period during which other market participants can join the trade. The public period lasts for at least 30 seconds, with any workup during the public period automatically extending the workup session. The session terminates 40 seconds after the initiating trade or, if it is extended, 30 seconds after the last workup. In contrast to continuous mid-market matching, the direction and size of interests are on display.

[45] For less frequently traded index CDSs, the GFI SEF offers periodic matching sessions, which are briefly discussed in the Internet Appendix.

[46] Current minimum sizes are USD 25 million for CDX.IG and USD 10 million for CDX.HY.

6.2 Data and Identification of Mid-Market Matches and Workups

The additional GFI data consist of the mid-market levels for continuous matching. On average, there are 132 and 151 mid-market levels per day for CDX.IG and CDX.HY, respectively. Together with the GFI bid and offer quote data, these data allow to identify whether trades were executed in the limit order book (i.e., at the best bid or offer), via mid-market matching (i.e., at the mid-market level), or using the workup protocol (i.e., at the transaction price of an initiating trade in the limit order book and before the respective workup session timed out; the Internet Appendix contains the details). Trades that satisfy neither of the above are subsumed into their own category. Some of these trades are voice-brokered RFQs.

Table 5 shows the fraction of trades and trading volume on the GFI SEF that is executed via the different trading protocols. For CDX.IG and CDX.HY, trades in the limit order book account for 19.2% and 15.8%, respectively, of the trading volume, mid-market matching accounts for 52.2% and 58.7%, and the workup protocol accounts for 19.9% and 15.5%.[47] Together, size-discovery trading protocols account for more than 70% of trading volume.[48]

[Table 5 about here.]

6.3 Transaction Costs Across Trading Protocols

Table 6 displays average effective half-spreads, realized half-spreads, and price impacts by trading protocol.[49] Trades in the limit order book have high transaction costs and price impacts. For CDX.IG, the average effective half-spread and price impact is 0.132 bps and 0.152 bps, respectively (vs. 0.098 bps and 0.060 bps across all D2D trades, see Table 2). The

[47] About half of the trades in the limit order book are subsequently worked up.

[48] The fraction of trades with unidentified trading protocol is higher in terms of volume than in terms of trades, indicating that these trades tend to be relatively large. Indeed, most block-sized trades have an unidentified trading protocol. As explained above, some of the trades with unidentified trading protocol are voice-brokered RFQs. Thus, voice brokers' ability to match dealers with offsetting inventory imbalances may explain why block-sized D2D trades have essentially no price impact (see Table 2).

[49] As for D2D trades in the previous sections, half-spreads and price impacts are with respect to the GFI mid-quote.

corresponding figures for CDX.HY are 0.722 bps and 0.698 bps (vs. 0.494 bps and 0.247 bps across all D2D trades).[50] The average price impacts exceed those of D2C trades reported in Table 2.

[Table 6 about here.]

Next, compare mid-market matches with trades in the limit order book. Mid-market matches have significantly lower transaction costs and price impacts than trades in the limit order book. For CDX.IG, the average effective half-spread and price impact is 0.055 bps and 0.036 bps, respectively. The corresponding figures for CDX.HY are 0.283 bps and 0.168 bps. That transaction costs are lower for mid-market matches is not surprising because the mid-market level is usually set somewhere between the inside quotes on the limit order book. That price impacts are lower for mid-market matches indicates a partial segmentation of the order flow, with a higher proportion of uninformed trades being executed via mid-market matching. This is consistent with Zhu's (2014) model of strategic venue selection by informed and liquidity traders. In his model, traders optimally choose between sending orders to a mid-point dark pool (roughly equivalent to continuous mid-market matching) and executing against limit orders. Sending an order to a dark pool involves a trade-off between potential price improvement and the risk of no execution. In equilibrium, liquidity traders prefer the dark pool, while informed traders prefer the certainty of executing against limit orders.

Finally, compare workups with trades in the limit order book. There are no significant differences in transaction costs. This is by design because a workup is executed at the price of the initiating trade in the limit order book. There are also no significant differences in price impacts. Because the duration of a workup session is much shorter than the 15-minute period over which price impact is measured, the price impact of a workup will include most

[50] At the same time, for each index the average effective half-spread is significantly lower than the average GFI bid-offer half-spread, which is 0.303 bps for CDX.IG and 1.649 bps for CDX.HY. That is, dealers are more likely to trade in the limit order book when bid-offer spreads are relatively narrow.

of the price impact of the initiating trade. The result, therefore, indicates that the additional price impact of a workup is close to zero.[51]

To further explore differences in price impacts across trading protocols, we extend the VECM in Section 5 by having separate D2D-trade-related variables for trades in the limit order book, mid-market matches, and workups. A residual category comprises trades with unidentified trading protocol that are executed on the GFI SEF as well as trades that are executed on other IDB SEFs. We resolve contemporaneous effects between the D2D-trade-related variables by allowing the residual D2D trades to contemporaneously affect the other D2D-trade-related variables, mid-market matches to contemporaneously affect trades in the limit order book and workups, and trades in the limit order book to contemporaneously affect workups. With the exception of the relation between trades in the limit order book and workups—which is determined by the design of the workup trading protocol—the imposed contemporaneous relations among the remaining pairs of D2D-trade-related variables do not affect our results because pairwise contemporaneous correlations are negligible.

Figure 5 shows the model-implied price impacts, which are consistent with Table 6. A trade in the limit order book has a high permanent price impact, which exceeds that of a D2C trade. A mid-market match has a significantly lower permanent price impact than a trade in the limit order book. Finally, the cointegrated VAR model separates the price impact of a workup from that of the initiating trade in the limit order book, with workups indeed having very little price impact at any horizon. That a workup has much lower price impact than the initiating trade in the limit order book is consistent with evidence from the interdealer Treasury market reported in Fleming and Nguyen (2015).

[Figure 5 about here.]

[51] This is confirmed by comparing the average price impact of those trades in the limit order book that are subsequently worked up with the average price impact of those that are not. For both indices, the average price impacts of worked-up and non-worked-up trades in the limit order book are not significantly different.

Overall, our results show that the low average transaction cost and price impact of D2D trades reported in Sections 4 and 5 mask significant heterogeneity across trading protocols; size-discovery protocols attract liquidity-motivated trading, while trades in the limit order book appear relatively informed—even more so than the average D2C trade.

7 Dealer Profits and Price Improvements

Finally, we estimate dealer profits from liquidity provision to clients and the price improvements that clients obtain vis-à-vis the inside quotes on the limit order book of the GFI SEF.

7.1 Dealer Profits from Liquidity Provision to Clients

We estimate dealer profits from liquidity provision to clients by the average daily profit on D2C trades in five-year on-the-run index CDSs, assuming that dealers immediately close their positions on the GFI SEF. Specifically, we compute, day by day, the trade-size-weighted average profit across all D2C trades and multiply it by the aggregate trading volume across D2C SEFs (from Clarus FT). In computing per trade profits, we consider two scenarios: in the first scenario, dealers close D2C trades at the mid-market level. In the second scenario, dealers close D2C trades at the inside quotes on the limit order book, with protection-buyer-initiated D2C trades being closed at the best offer and protection-seller-initiated D2C trades being closed at the best bid.[52]

In the first scenario, average daily profits from liquidity provision are USD 0.437 million for CDX.IG and USD 0.811 million for CDX.HY, or USD 1.248 million in total. However, this calculation of profits assumes that the mid-market level is executable, which it only is if

[52] We require mid-market levels and quotes to come from within 15 minutes prior to trade execution. Therefore, per trade profits cannot be computed for a few trades and we drop these trades from the computation of daily trade-size-weighted profits.

there are opposing unfilled interests for matching. In the second scenario that uses executable inside quotes, profits from liquidity provision are negative.[53] This suggests that dealers only make profits through their willingness to bear inventory risk (see, e.g., Grossman and Miller (1988)).

7.2 Price Improvements vis-à-vis the GFI Limit Order Book

The results above suggest that clients who value immediacy would typically not be able to reduce transaction costs by executing trades on the limit order book of the GFI SEF.[54] Table 7 quantifies the price improvements for D2C trades with respect to the inside quotes on the GFI limit order book.[55] Price improvements are large and mostly positive. The average price improvements are 0.229 bps for CDX.IG and 1.291 bps for CDX.HY, and price improvements are strictly positive for 95.8% and 96.4% of the trades in CDX.IG and CDX.HY, respectively. To verify that our results are not sensitive to the signing of D2C trades, the table also reports the percentages of trades with transaction prices strictly within the bid-offer spread; these are 95.3% for CDX.IG and 96.1% for CDX.HY.

[Table 7 about here.]

As an illustration, Figure 6 displays transaction prices of D2C trades in CDX.IG on May 6, 2015—the representative trading day from Figure 2—along with the bid-offer spread on the GFI limit order book. Most D2C trades are executed at prices strictly within the bid-offer spread (135 or 97.1% of the 139 D2C trades) and close to the mid-market level. Price improvements from the inside quotes are substantial (0.224 bps, on average).

[53] Trades can be closed at the inside quotes provided that the limit order book is sufficiently deep at the inside. We abstract from this issue when computing per trade profits because the GFI data does not include depth.

[54] Transaction costs can only be reduced at the cost of execution risk either by posting limit orders or by matching at the mid-market level.

[55] Price improvement is defined as $o_t - p_t$ if $q_t = 1$ and $p_t - b_t$ if $q_t = -1$, where b_t and o_t are the latest GFI bid and offer quotes, respectively, in the 15-minute period prior to trade execution.

[Figure 6 about here.]

The price improvements in Table 7 are sizeable when put in relation to the average transaction costs of D2C trades reported in Table 2. The magnitudes of the price improvements mainly reflect the wide bid-offer spreads on the GFI limit order book. However, an additional factor is the relation between Markit and GFI quotes around trade execution with the side at which trades occur typically being favorably priced in the D2C segment of the market. This is evident from Figure 7 which shows the average bid-offer spreads of the Markit and GFI quotes that prevail at execution of protection-buyer-initiated (Panel A) and protection-seller-initiated (Panel B) D2C trades in CDX.IG (a similar pattern holds true for CDX.HY, see Internet Appendix). For buyer-initiated trades, the Markit mid-quote tends to be below the GFI mid-quote so that the sum of the average transaction cost (0.132 bps) and the average price improvement (0.230 bps) exceeds the average GFI bid-offer half-spread (0.302 bps). Similarly, for seller-initiated trades, the Markit mid-quote tends to exceed the GFI mid-quote so that the sum of the average transaction cost (0.135 bps) and the average price improvement (0.229 bps) again exceeds the average GFI bid-offer half-spread (0.300 bps).[56] For both buyer- and seller-initiated trades, clients are able to transact at prices that are close the GFI mid-quote and the mid-market level.

[Figure 7 about here.]

Our findings are different from Bjønnes et al. (2016) who show that most D2C trades in the spot FX market exhibit a positive markup relative to the inside quotes in the interdealer market, but they are in line with Dunne et al. (2015) who show that most D2C trades in the European government bond market occur within the interdealer bid-offer spread.

[56] Note that the average transaction cost across all D2C trades in CDX.IG (0.138 bps, see Table 2) is slightly higher than the numbers in Figure 7. The reason is that Figure 7 requires both Markit and GFI quotes to be available within 15 minutes prior to trade execution, while Table 2 requires only Markit quotes to be available.

8 Conclusion

Using transaction data, we study the market structure and transaction costs of index CDSs after the implementation of the Dodd-Frank Act. Despite a regulatory effort to promote all-to-all trading, a two-tiered market structure persists with dealer-to-client (D2C) trades and interdealer (D2D) trades taking place on distinct trading platforms. Average transaction cost and price impact are higher for D2C trades and increase with trade size, bid-offer spreads, and volatility. Price impact is largely permanent; the relatively high permanent price impact of the average D2C trade is suggestive of clients trading on information, while the relatively low permanent price impact of the average D2D trade is consistent with dealers mainly using the interdealer market to manage their inventory risk. Virtually all D2C trades are executed via request for quote, but number of different trading protocols are used for D2D trades, and we document significant heterogeneity across trading protocols on the main interdealer trading platform. The dominant trading protocol is mid-market matching for which average transaction cost and price impact are very low, but execution is uncertain; in contrast, trades in the limit order book have high average transaction cost and price impact, but no execution risk. D2C prices are typically better than the contemporaneous inside quotes on the main interdealer limit order book, indicating that clients who value immediacy could not get better execution by sending marketable orders to the interdealer market. This may explain the endurance of the two-tiered market structure.

Appendices

A Dodd-Frank Act Implementation Timeline

Jul 21, 2010	President Obama signs the Dodd-Frank Wall Street Reform and Consumer Protection Act (the "Dodd-Frank Act") into law.
Jan 9, 2012	The CFTC publishes the final rules for real-time public reporting of swap transaction data.
Nov 28, 2012	The CFTC announces mandatory central clearing of certain swaps in three implementation phases. In the first phase, swap dealers and private funds active in swap markets (so-called Category 1 Entities) are required to clear their swap trades. In the second phase, financial entities other than Category 3 Entities (so-called Category 2 Entities) are required to clear their swap trades. In the third phase, investment managers and pension plans (so-called Category 3 Entities) are required to clear their swap trades. End-users, i.e., non-financial entities hedging commercial risks, are exempt from mandatory central clearing.
Dec 31, 2012	Real-time public reporting of index CDS trades becomes mandatory for swap dealers.
Feb 28, 2014	Real-time public reporting of index CDS trades becomes mandatory for major swap market participants.
Mar 11, 2013	Central clearing becomes mandatory for Category 1 Entities trading CDX.IG or CDX.HY (for trades in the five-year contract tenor, mandatory central clearing applies to series 11 and all subsequent series).
Apr 10, 2013	Real-time public reporting of index CDS trades becomes mandatory for any swap market participant.
May 31, 2013	The CFTC publishes the final block-trade rules.[57]
Jun 4, 2013	The CFTC publishes the final rules for SEF compliance and mandatory trade execution on SEFs. These specify: (i) the (electronic) trading platforms that are required to be registered as SEFs and the prescribed methods of execution for trades in swaps that are subject to mandatory trade execution on SEFs (either execution against orders resting on a SEF's order book or execution against a response to a RFQ facilitated by a SEF and transmitted to at least three other SEF participants) and (ii) the process that SEFs can initiate (via so-called made available to trade determinations demonstrating sufficiently liquid trading) to get CFTC approval for mandatory trade execution of certain swaps on SEFs.[58]

[57] Block trades are exempt from the trade execution requirement and may be publicly disseminated with delay.
[58] Swaps eligible for made available to trade determinations have to be subject to mandatory central clearing.

Jun 10, 2013	Central clearing becomes mandatory for Category 2 Entities trading CDX.IG or CDX.HY.
Jul 30, 2013	Block trade rules become effective, with index CDS trades of notional amounts exceeding certain par-spread- and contract-tenor-dependent minimum block sizes being defined as block trades (note that minimum block sizes defining block trades do not necessarily coincide with the sizes at which publicly disseminated notional amounts are being capped).[59]
Aug 5, 2013	Closing date for applications to become a CFTC-registered SEF according to (i) from above. Temporarily registered SEFs are free to initiate made available to trade determinations that are subject to CFTC approval as set forth in (ii) from above.
Sep 9, 2013	Central clearing becomes mandatory for Category 3 Entities trading CDX.IG or CDX.HY.
Oct 2, 2013	The first temporarily registered SEFs start operating.
Jan 28, 2014	The CFTC approves a made available to trade determination for on-the-run and immediate off-the-run index CDSs on CDX.IG, CDX.HY, iTraxx Europe, and iTraxx Europe Crossover with five-year contract tenors.
Feb 26, 2014	The approved made available to trade determination becomes effective and all trades in the above-mentioned index CDSs (not qualifying as block trades or not being end-user exempt) must be executed on SEFs.

[59] Prior to July 30, 2013, all index CDS trades were publicly disseminated with delay and for trades of notional amounts exceeding USD 100 million, the disseminated notional amounts were capped at USD 100 million.

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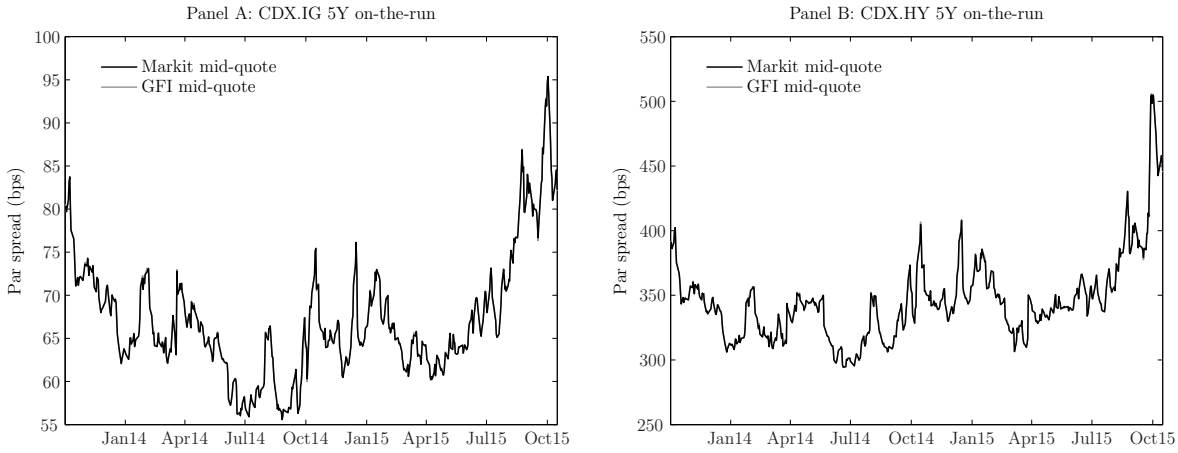

Figure 1: Daily Mid-Quotes.

Panels A and B show daily sample means of mid-quotes for five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively. Quotes are in terms of par spreads and expressed in basis points. The sample period is October 2, 2013 to October 16, 2015 and comprises 223,324 (546,916) and 197,042 (431,894) Markit (GFI) quotes for five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively.

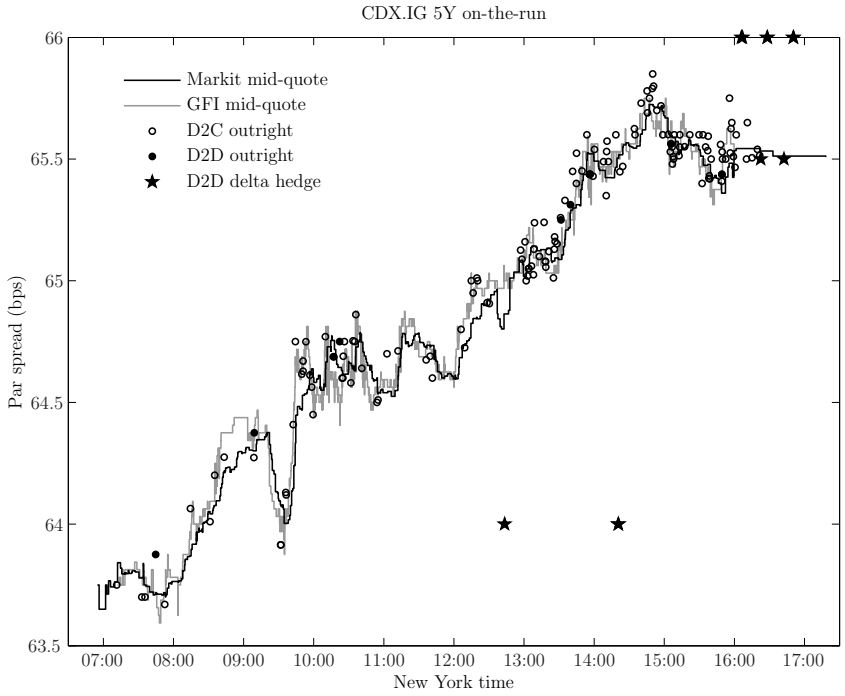

Figure 2: Transaction Prices and Mid-Quotes on May 6, 2015.

The figure shows transaction prices and mid-quotes for the five-year index CDS contract on series 24 of CDX.IG on May 6, 2015. Circles indicate outright trades and stars indicate delta hedges of index swaption trades. Unfilled symbols indicate dealer-to-client (D2C) trades and filled symbols indicate dealer-to-dealer (D2D) trades. The black line is the mid-quote based on Markit intraday composite quotes and the gray line is the mid-quote based on inside quotes on the limit order book of the GFI Swaps Exchange. Both transaction prices and quotes are in terms of par spreads and expressed in basis points (bps). Series 24 of CDX.IG was on-the-run on May 6, 2015.

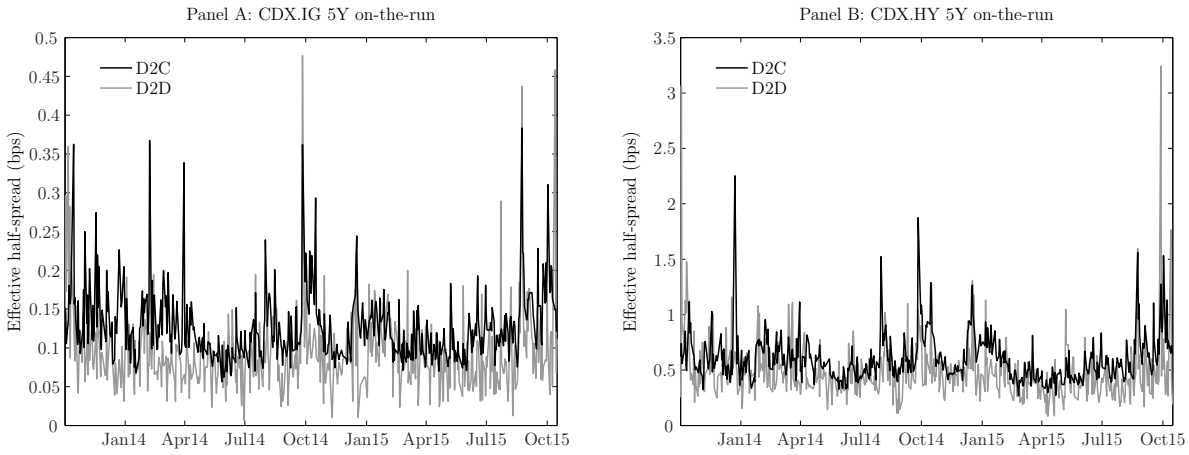

Figure 3: Daily Transaction Costs by Market Segment.

Panels A and B show daily sample means of effective half-spreads for outright dealer-to-client (D2C) and dealer-to-dealer (D2D) trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively. The effective half-spread is defined as $q_t \times (p_t - m_t^{\tau})$, where τ indicates whether the trade is D2C or D2D, p_t is the transaction price, and m_t^{D2C} and m_t^{D2D} are the latest Markit and GFI mid-quotes, respectively, in the 15-minute period prior to trade execution. Both transaction prices and quotes are in terms of par spreads and expressed in basis points (bps). Trade direction, q_t, is inferred by the Lee and Ready (1991) algorithm. The sample period is October 2, 2013 to October 16, 2015 and comprises 51,237 (9,132) and 73,115 (10,658) outright D2C (D2D) trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively.

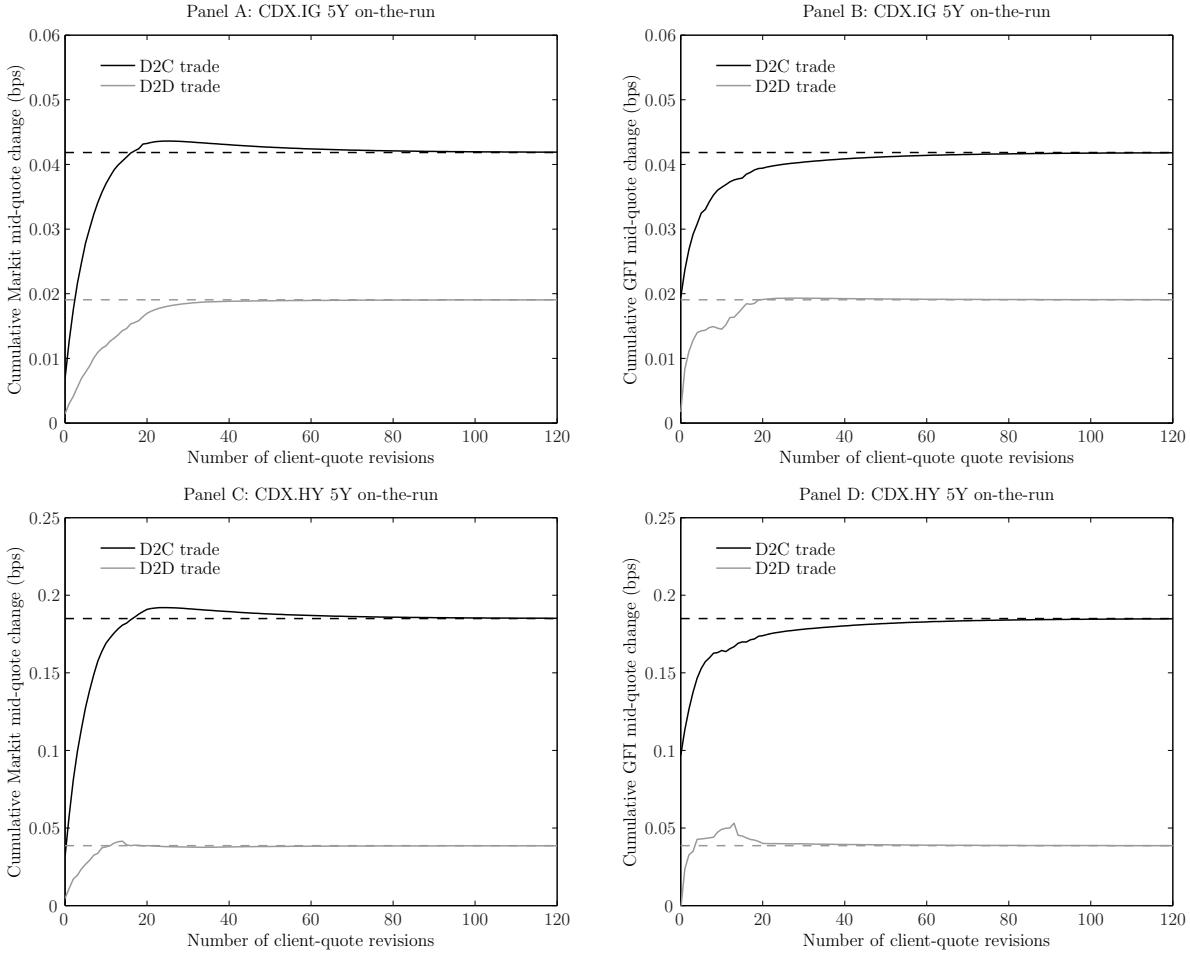

Figure 4: Price Impacts by Market Segment.

The panels show cumulative changes of Markit (Panels A and C) and GFI (Panels B and D) mid-quotes in response to either a single protection-buyer-initiated dealer-to-client (D2C; solid black lines) trade or a single protection-buyer-initiated dealer-to-dealer (D2D; solid light gray lines) trade. The trades are outright five-year on-the-run index CDS trades in CDX.IG (Panel A and B) and CDX.HY (Panel C and D). Cumulative quote changes are implied by event-time vector error correction models for Markit and GFI mid-quote changes and sums of signed D2C and D2D trades that occur between events. Revisions of client quotes (as captured by updates of Markit quotes) constitute events. Dashed horizontal lines mark permanent price impacts as captured by the long-run cumulative quote change. Quotes are in terms of par spreads and expressed in basis points (bps). The sample period is October 2, 2013 to October 16, 2015 and comprises 212,103 and 183,861 client-quote revisions for CDX.IG and CDX.HY, respectively.

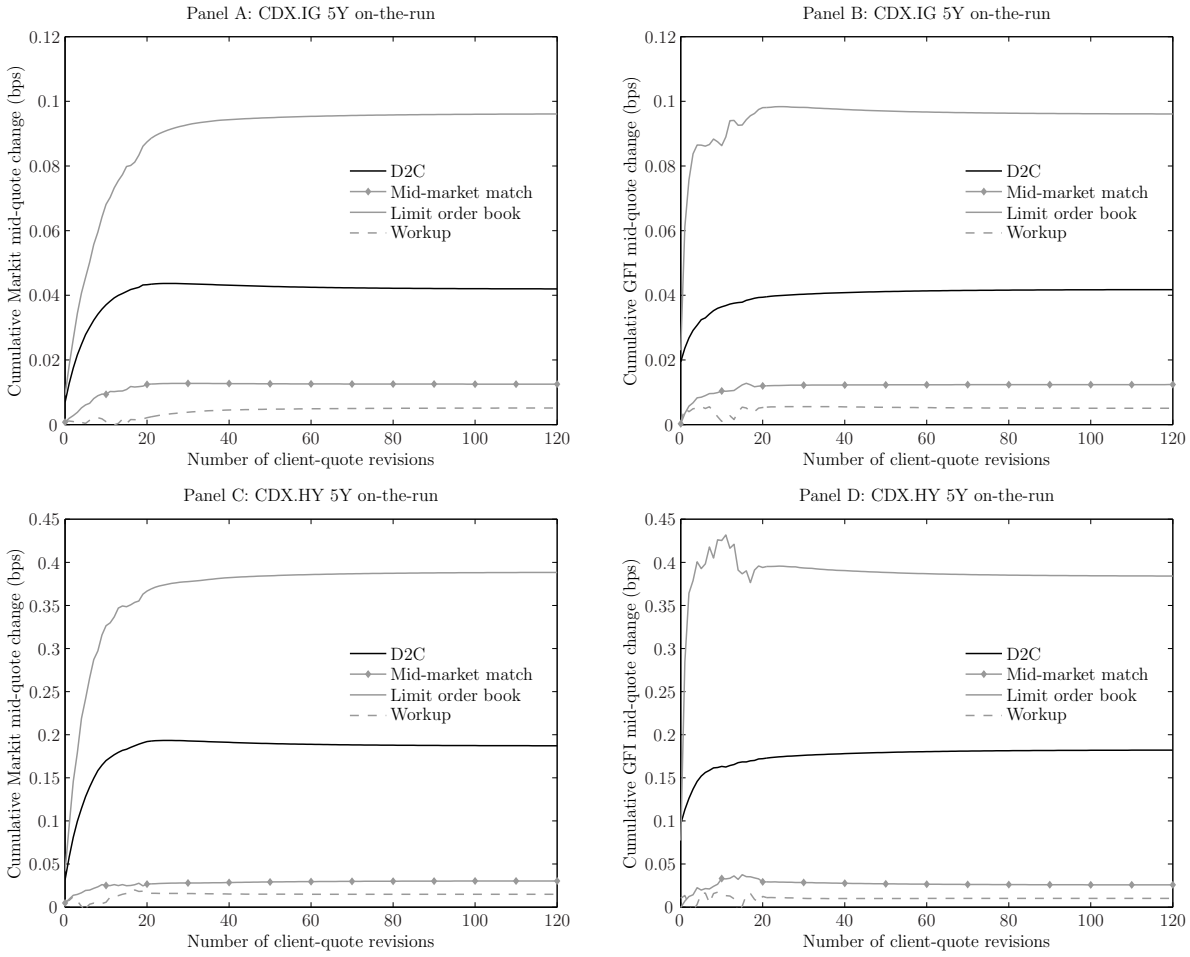

Figure 5: Price Impacts by Trading Protocol.

The panels show cumulative changes of Markit (Panels A and C) and GFI (Panels B and D) mid-quotes in response to either a single protection-buyer-initiated dealer-to-client (D2C) trade (solid black lines) or a single protection-buyer-initiated dealer-to-dealer (D2D) mid-market match (marked solid light gray lines), trade in the limit order book (solid light gray lines), or workup (dashed light gray lines). The trades are outright five-year on-the-run index CDS trades in CDX.IG (Panel A and B) and CDX.HY (Panel C and D). Cumulative quote changes are implied by event-time vector error correction models for Markit and GFI mid-quote changes and sums of signed D2C and D2D trades that occur between events, with separate sums for mid-market matches, trades in the limit order book, workups (all of which are executed on the GFI Swaps Exchange), and the remaining D2D trades (which are executed either on the GFI Swaps Exchange by an unidentified trading protocol or on another interdealer broker SEF). Revisions of client quotes (as captured by updates of Markit quotes) constitute events. Quotes are in terms of par spreads and expressed in basis points (bps). The sample period is October 2, 2013 to October 16, 2015 and comprises 212,103 and 183,861 client-quote revisions for CDX.IG and CDX.HY, respectively.

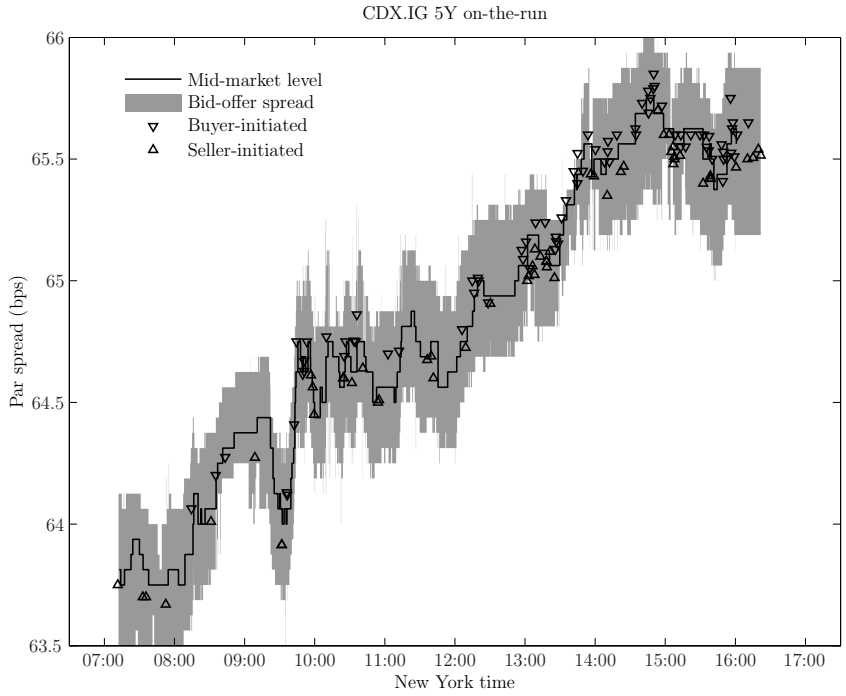

Figure 6: Dealer-To-Client Trades and Interdealer Bid-Offer Spread on May 6, 2015.
The figure shows transaction prices of outright dealer-to-client trades, the mid-market level, and the bid-offer spread on the limit order book of the GFI Swaps Exchange for the five-year index CDS contract on series 24 of CDX.IG on May 6, 2015. Downward-pointing triangles indicate protection-buyer-initiated trades and upward-pointing triangles indicate protection-seller-initiated trades. The black line is the mid-market level. The gray area is spanned by the best bid and offer on the limit order book of the GFI Swaps Exchange. Transaction prices, the mid-market level, and bid and offer quotes are in terms of par spreads and expressed in basis points (bps). Series 24 of CDX.IG was on-the-run on May 6, 2015.

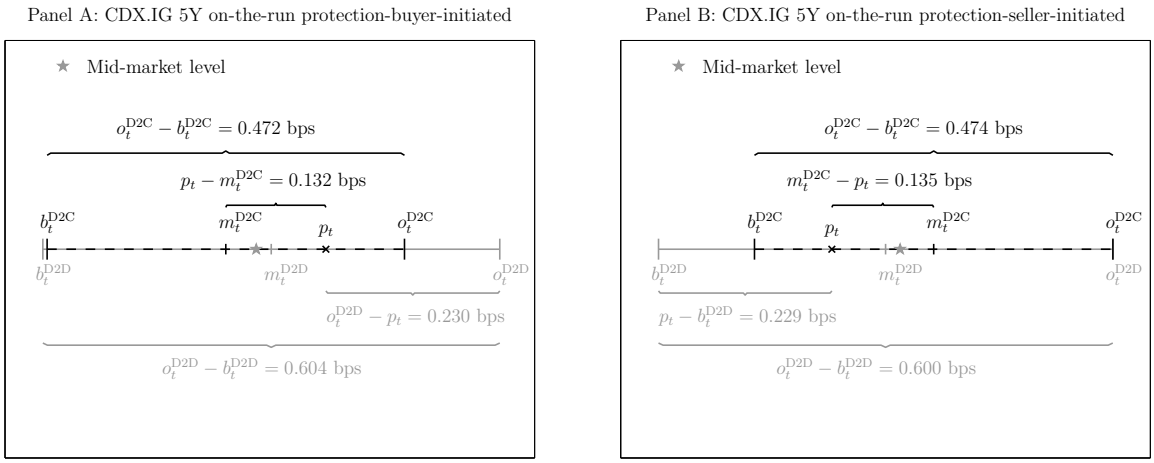

Figure 7: Relation Among Quotes at Execution of Dealer-to-Client Trades.

Panels A and B show the average relation among Markit and GFI quotes at execution of protection-buyer- and protection-seller-initiated dealer-to-client (D2C) trades, respectively, in five-year on-the-run index CDSs on CDX.IG. p_t is the transaction price, b_t^{D2C} and b_t^{D2D} are the latest Markit and GFI bid quotes, respectively, in the 15-minute period prior to trade execution, o_t^{D2C} and o_t^{D2D} are the latest offer quotes, and m_t^{D2C} and m_t^{D2D} are the corresponding mid-quotes. The dashed black lines mark the spread between Markit bid and offer quotes and the gray lines mark the spread between the GFI bid and offer quotes. The gray star is the mid-market level that prevails at trade execution. The sample period is October 2, 2013 to October 16, 2015 and comprises 24,288 (24,767) outright protection-buyer-initiated (protection-seller-initiated) D2C trades in five-year on-the-run index CDSs on CDX.IG.

		USD MM		% of Trds						% of Vlm			
SEF	Trds	Sz	Vlm (ActVlm)	5Y	OTR	Bspk	Clrd	Blck	Cppd	Crv	Rll	Swptn	Trnch
Panel A1: CDX.IG *Dealer-To-Client*													
Bloomberg SEF	95	50	5,394 (7,681)	99.7	93.5	0.0	100.0	20.1	19.4	0.1	4.5	0.0	—
ICE Swap Trade	3	44	154 (318)	98.0	90.1	0.0	84.1	27.2	32.5	0.1	0.0	16.9	6.5
MarketAxess SEF	5	37	282 (533)	99.0	89.7	0.0	100.0	25.0	26.1	0.2	13.1	0.6	—
TW SEF	11	50	605 (1,310)	98.9	84.8	0.0	100.0	28.4	31.5	0.0	7.3	—	—
Total	114	50	6,434 (9,843)	99.6	92.4	0.0	99.6	21.3	21.2	0.1	5.0	0.4	0.2
Panel A2: CDX.IG *Dealer-To-Dealer*													
GFI Swaps Exchange	17	50	773 (808)	96.1	91.6	0.7	99.3	0.0	3.9	4.7	16.9	3.2	1.9
ICAP SEF	1	25	58 (71)	75.8	71.2	0.0	94.9	0.0	9.7	0.0	0.0	7.4	51.8
tpSEF	6	50	351 (445)	94.8	86.9	0.0	96.0	2.2	14.1	4.7	21.9	1.7	0.0
Tradition SEF	0	79	19 (30)	78.7	63.8	0.0	72.4	0.0	27.6	0.0	0.0	61.6	35.0
Total	24	50	1,201 (1,354)	94.8	89.3	0.5	98.0	0.5	6.8	4.4	17.3	3.9	4.3
Panel B1: CDX.HY *Dealer-To-Client*													
Bloomberg SEF	140	10	2,583 (2,840)	100.0	93.9	0.0	100.0	17.8	1.4	0.0	7.8	0.0	—
ICE Swap Trade	3	5	68 (77)	99.7	87.9	0.0	91.0	28.3	7.2	0.0	0.1	9.9	6.5
MarketAxess SEF	6	10	138 (150)	99.9	90.8	0.0	100.0	24.5	3.9	0.0	12.1	0.2	—
TW SEF	15	16	434 (639)	100.0	87.0	0.0	100.0	35.8	9.9	0.0	15.9	—	—
Total	164	10	3,224 (3,705)	100.0	93.0	0.0	99.8	19.9	2.3	0.0	8.9	0.2	0.1
Panel B2: CDX.HY *Dealer-To-Dealer*													
GFI Swaps Exchange	17	10	209 (211)	99.9	94.1	0.7	99.2	0.0	0.9	0.0	21.1	4.2	0.5
ICAP SEF	1	10	17 (25)	98.6	68.9	0.0	87.8	0.0	0.7	0.0	0.0	13.1	45.8
tpSEF	8	10	147 (157)	99.6	89.1	0.0	96.2	2.7	2.6	0.0	26.1	1.0	0.0
Tradition SEF	0	20	6 (8)	95.0	68.3	0.0	79.2	0.0	1.0	0.0	0.0	49.6	36.8
Total	27	10	380 (402)	99.7	91.5	0.4	97.8	0.9	1.4	0.0	21.7	4.1	3.0

Table 1: Descriptive Statistics of On-SEF Index CDS Trades.

The table shows descriptive statistics of on-SEF dealer-to-client (D2C) and dealer-to-dealer (D2D) index CDS trades in CDX.IG and CDX.HY by SEF. Trds is the number of trades per day computed as the total number of trades divided by the number of trading days in the sample period, 511. Sz is median trade size. Vlm is daily volume computed as the aggregate notional amount divided by the number of trading days in the sample period (ActVlm is actual daily volume computed equivalently using daily volumes reported by SEFs). 5Y (OTR) is the percentage of trades in five-year (on-the-run) index CDSs. Bspk is the percentage of trades with bespoke contract terms. Clrd is the percentage of cleared trades. Blck is the percentage of trades qualifying as block trades. Cppd is the percentage of trades that are disseminated with capped notional amounts. Crv (Rll) is the percentage of the aggregate notional amount that is identified as being part of curve trades (index rolls). Swptn (Trnch) is the percentage of the aggregate notional amount that is identified as being index swaption (index tranche swap) delta hedges. The sample period is October 2, 2013 to October 16, 2015 and comprises 58,224 (12,397) and 83,773 (13,585) D2C (D2D) trades in CDX.IG and CDX.HY, respectively.

	Dealer-To-Client			*Dealer-To-Dealer*			*D2C-D2D*		
Trade Size	Effc Sprd	Rlzd Sprd	Prc Imp	Effc Sprd	Rlzd Sprd	Prc Imp	Effc Sprd	Rlzd Sprd	Prc Imp
Panel A: CDX.IG									
≤ 25	0.122	0.036	0.086	0.088	0.032	0.056	0.034**	0.004	0.030**
25–50	0.132	0.026	0.106	0.106	0.030	0.076	0.026**	-0.004	0.030**
50–100	0.143	0.025	0.118	0.114	0.079	0.034	0.029**	-0.055**	0.084**
> 100	0.171	0.057	0.114	0.148	0.146	0.002	0.023	-0.089**	0.112**
Total	0.138	0.036	0.102	0.098	0.038	0.060	0.040**	-0.002	0.042**
Panel B: CDX.HY									
≤ 5	0.604	0.179	0.424	0.433	0.256	0.178	0.171**	-0.076*	0.247**
5–10	0.637	0.137	0.500	0.523	0.220	0.303	0.114**	-0.084**	0.198**
10–25	0.701	0.134	0.566	0.506	0.291	0.215	0.195**	-0.156**	0.351**
> 25	0.804	0.316	0.489	0.620	0.417	0.203	0.184**	-0.101	0.286**
Total	0.676	0.183	0.492	0.494	0.248	0.247	0.181**	-0.064**	0.246**

Table 2: Transaction Costs and Price Impacts by Market Segment.

Panels A and B show sample means of effective half-spreads (EffcSprd), realized half-spreads (RlzdSprd), and price impacts (PrcImp) for outright dealer-to-client (D2C) and dealer-to-dealer (D2D) trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively. Sample means are separately computed by quartiles of the trade size distribution and in total. EffcSprd is defined as $q_t \times (p_t - m_t^\tau)$, where τ indicates whether the trade is D2C or D2D, p_t is the transaction price, and m_t^{D2C} and m_t^{D2D} are the latest Markit and GFI mid-quotes, respectively, in the 15-minute period prior to trade execution. RlzdSprd is defined as $q_t \times (p_t - m_{t+\Delta}^\tau)$, where $m_{t+\Delta}^{\text{D2C}}$ and $m_{t+\Delta}^{\text{D2D}}$ are the respective mid-quotes that prevail 15 minutes after trade execution. PrcImp is defined as $q_t \times (m_{t+\Delta}^\tau - m_t^\tau)$. Both transaction prices and quotes are in terms of par spreads and expressed in basis points. Trade size is in USD million. Trade direction, q_t, is inferred by the Lee and Ready (1991) algorithm. Rejection of a regression-based t-test for the null hypothesis that D2C and D2D sample means are identical at the 1% and 5% level is denoted by ** and *, respectively, with inference based on the Newey and West (1987) estimate of the covariance matrix of coefficient estimates. The sample period is October 2, 2013 to October 16, 2015 and comprises 51,237 (9,132) and 73,115 (10,658) outright D2C (D2D) trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively.

	CDX.IG			CDX.HY		
	EffcSprd	RlzdSprd	PrcImp	EffcSprd	RlzdSprd	PrcImp
SMLL	0.117**	0.031**	0.086**	0.591**	0.164**	0.427**
	(69.04)	(13.33)	(30.73)	(77.91)	(16.45)	(31.63)
SMLL×(−D2D)	0.023**	0.005	0.018**	0.138**	-0.081*	0.219**
	(7.22)	(0.80)	(3.05)	(7.07)	(-2.12)	(6.02)
MDM	0.124**	0.021**	0.103**	0.602**	0.118**	0.484**
	(73.18)	(8.11)	(31.37)	(76.13)	(11.62)	(34.13)
MDM×(−D2D)	0.011**	-0.005	0.016*	0.056**	-0.093**	0.149**
	(3.76)	(-0.68)	(2.39)	(3.98)	(-3.36)	(5.14)
LRG	0.134**	0.020**	0.114**	0.661**	0.113**	0.548**
	(65.00)	(6.73)	(31.67)	(66.72)	(8.77)	(28.37)
LRG×(−D2D)	0.018**	-0.052**	0.070**	0.145**	-0.164**	0.309**
	(3.17)	(-4.58)	(6.98)	(6.94)	(-3.66)	(6.89)
BLCK	0.160**	0.050**	0.110**	0.781**	0.287**	0.494**
	(65.29)	(13.61)	(26.56)	(68.15)	(20.08)	(28.28)
BLCK×(−D2D)	0.009	-0.088**	0.097**	0.129**	-0.098	0.227**
	(0.59)	(-3.77)	(6.01)	(2.59)	(-1.04)	(3.00)
RFRNC	0.020**	0.031**	-0.010*	0.113**	0.154**	-0.041
	(7.92)	(6.29)	(-2.24)	(6.14)	(5.57)	(-1.66)
BASD2C	0.381**	-0.029	0.410**	0.270**	0.029	0.242**
	(7.11)	(-0.49)	(4.17)	(10.23)	(0.91)	(5.15)
BASD2D	0.039**	0.027*	0.011	0.037**	0.026**	0.012
	(4.41)	(2.24)	(0.75)	(5.22)	(3.01)	(1.00)
SPRD/100	0.016	0.107**	-0.091	0.069*	0.052	0.017
	(0.60)	(2.63)	(-1.76)	(2.16)	(1.68)	(0.33)
VLTLTY	0.197**	-0.169**	0.365**	1.285**	-0.521**	1.805**
	(6.39)	(-3.93)	(6.18)	(7.53)	(-2.95)	(6.21)
N	58,461	58,461	58,461	80,956	80,956	80,956

Table 3: Regressions Controlling for Trade Characteristics and Market Conditions.

The table shows OLS estimates of regression specifications that control for selection bias in the comparison of effective half-spreads (EffcSprd), realized half-spreads (RlzdSprd), and price impacts (PrcImp) across outright dealer-to-client (D2C) and dealer-to-dealer (D2D) trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY (t-statistics based on Newey and West (1987) standard errors are shown in parenthesis). EffcSprd is defined as $q_t \times (p_t - m_t^\tau)$, where τ indicates whether the trade is D2C or D2D, p_t is the transaction price, and m_t^{D2C} and m_t^{D2D} are the latest Markit and GFI mid-quotes, respectively, in the 15-minute period prior to trade execution. RlzdSprd is defined as $q_t \times (p_t - m_{t+\Delta}^\tau)$, where $m_{t+\Delta}^{\text{D2C}}$ and $m_{t+\Delta}^{\text{D2D}}$ are the respective mid-quotes that prevail 15 minutes after trade execution. PrcImp is defined as $q_t \times (m_{t+\Delta}^\tau - m_t^\tau)$. Both transaction prices and quotes are in terms of par spreads and expressed in basis points (bps). Trade direction, q_t, is inferred by the Lee and Ready (1991) algorithm. The explanatory variables include dummy variables for small- (SMLL), medium- (MDM), large- (LRG), and block-sized (BLCK) trades (cutoffs for trade-size dummies are the quartiles of the trade size distribution; USD 25, USD 50, and USD 100 MM for CDX.IG and USD 5, USD 10, and USD 25 MM for CDX.HY), their interactions with the negative of a dummy variable for D2D trades (D2D), a dummy variable for trades with transaction prices at typical reference levels (RFRNC; par spread multiples 0.5 bps for CDX.IG and price multiples of 0.125% for CDX.HY), the bid-offer spreads of the latest Markit (BASD2C) and GFI (BASD2D) quotes for the five-year on-the-run index CDS, the end-of-day composite spread for the five-year on-the-run index CDS (SPRD), and the end-of-day implied volatility of three-month at-the-money swaptions on the five-year on-the-run index CDS (VLTLTY). Continuous explanatory variables are demeaned. Statistical significance at the 1% and 5% level is denoted by ** and *, respectively. The sample period is October 2, 2013 to October 16, 2015 and comprises 49,425 (9,036) and 70,628 (10,328) outright D2C (D2D) trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively.

	z_{t-1}	$\sum_{j=1}^{20} \Delta m_{t-j}^{\text{D2C}}$	Δm_t^{D2D}	$\sum_{j=1}^{20} \Delta m_{t-j}^{\text{D2D}}$	x_t^{D2C}	$\sum_{j=1}^{20} x_{t-j}^{\text{D2C}}$	x_t^{D2D}	$\sum_{j=1}^{20} x_{t-j}^{\text{D2D}}$
Panel A1: CDX.IG								
Δm_t^{D2C}	-0.037	-0.116	0.111	0.587	0.005	0.010	0.001	0.001
	(-50.35)	(-9.86)	(100.10)	(47.77)	(43.63)	(23.09)	(6.15)	(1.21)
Δm_t^{D2D}	0.029	0.240		-0.119	0.019	0.005	0.002	0.014
	(20.31)	(10.43)		(-4.96)	(93.46)	(5.72)	(4.33)	(8.62)
x_t^{D2C}	-0.231	-0.889		3.485		0.222		-0.001
	(-15.56)	(-3.71)		(13.92)		(25.06)		(-0.05)
x_t^{D2D}	0.069	0.293		-0.583	0.002	0.012		0.144
	(8.75)	(2.32)		(-4.42)	(2.00)	(2.64)		(16.73)
Panel A2: CDX.HY								
Δm_t^{D2C}	-0.038	-0.189	0.099	0.613	0.022	0.045	0.005	-0.001
	(-46.43)	(-14.43)	(89.75)	(45.71)	(45.92)	(23.89)	(4.69)	(-0.19)
Δm_t^{D2D}	0.040	0.264		-0.335	0.097	0.026	-0.003	0.041
	(23.09)	(9.56)		(-11.87)	(97.58)	(6.56)	(-1.27)	(4.76)
x_t^{D2C}	-0.065	-0.372		1.004		0.275		-0.004
	(-15.97)	(-5.72)		(15.14)		(29.81)		(-0.19)
x_t^{D2D}	0.015	0.043		-0.140	-0.002	0.008		0.166
	(8.50)	(1.49)		(-4.75)	(-2.22)	(1.96)		(18.43)

Panel B: Permanent Price Impact

	CDX.IG			CDX.HY		
	D2C	D2D	D2C − D2D	D2C	D2D	D2C − D2D
Ψ	0.042	0.019	0.023	0.185	0.039	0.146
	(34.63)	(9.07)	(9.44)	(37.84)	(3.87)	(13.19)

Panel C: Price Discovery

	CDX.IG			CDX.HY		
	D2C	D2D	Trade-Unrelated	D2C	D2D	Trade-Unrelated
R^2	15.07	0.87	84.07	21.12	0.18	78.70

Table 4: VECM Estimates.

The table shows coefficient estimates of event-time vector error correction models (VECMs) for Markit and GFI mid-quote changes (Δm_t^{D2C} and Δm_t^{D2D}, respectively) and sums of signed dealer-to-client (D2C) and dealer-to-dealer (D2D) trades that occur between events (x_t^{D2C} and x_t^{D2D}, respectively). Revisions of client quotes (as captured by updates of Markit quotes) constitute events. Panels A1 and A2 show VECM coefficient estimates (t-statistics based on OLS standard errors are shown in parenthesis). Coefficient estimates of contemporaneous variables are separated from coefficient estimates of lagged variables and sums of the latter are reported in columns that show sums of lagged variables. Panel B shows permanent price impact estimates (Ψ; t-statistics based on OLS standard errors are shown in parenthesis) as captured by the model-implied long-run cumulative quote change (in basis points) in response to either a single protection-buyer-initiated D2C trade or a single protection-buyer-initiated D2D trade as well as the difference in price impacts of D2C and D2D trades. Panel C shows a model-implied variance decomposition of efficient price innovations into trade-related and trade-unrelated components (in percent of the variance of efficient price innovations). Quotes are in terms of par spreads and trade direction used to sign trades is inferred by the Lee and Ready (1991) algorithm. The sample period is October 2, 2013 to October 16, 2015 and comprises 212,103 and 183,861 client-quote revisions for CDX.IG and CDX.HY, respectively.

Trading Protocol	% of Trds	% of Vlm
Panel A: CDX.IG		
Limit order book	19.1	19.2
Workup protocol	18.4	19.9
Mid-market matching	54.8	52.2
Unidentified protocol	7.7	8.8
Panel B: CDX.HY		
Limit order book	15.3	15.8
Workup protocol	16.0	15.5
Mid-market matching	61.4	58.7
Unidentified protocol	7.3	10.0

Table 5: Percentage of Trades and Volume by Trading Protocol.

Panels A and B show percentages of trades and trading volume by trading protocol for outright trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively, that are executed on the GFI Swaps Exchange. The sample period is October 2, 2013 to October 16, 2015 and comprises 7,049 and 7,414 outright trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively.

Trading Protocol	Effc Sprd	Rlzd Sprd	Prc Imp
Panel A: CDX.IG			
Limit order book	0.132	-0.020	0.152
Workup protocol	0.131	-0.019	0.150
Mid-market matching	0.055**	0.019**	0.036**
Unidentified protocol	0.151	0.132**	0.019**
Panel B: CDX.HY			
Limit order book	0.722	0.024	0.698
Workup protocol	0.698	0.024	0.674
Mid-market matching	0.283**	0.115*	0.168**
Unidentified protocol	0.864	0.666**	0.198**

Table 6: Transaction Costs and Price Impacts by Trading Protocol.

Panels A and B show sample means of effective half-spreads (EffcSprd), realized half-spreads (RlzdSprd), and price impacts (PrcImp) of outright trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively, that are executed on the GFI Swaps Exchange. Sample means are separately computed for trades in the limit order book, mid-market matches, workups, and trades with unidentified trading protocol. EffcSprd is defined as $q_t \times (p_t - m_t^{\text{D2D}})$, where p_t is the transaction price and m_t^{D2D} is the latest GFI mid-quote in the 15-minute period prior to trade execution. RlzdSprd is defined as $q_t \times (p_t - m_{t+\Delta}^{\text{D2D}})$, where $m_{t+\Delta}^{\text{D2D}}$ is the GFI mid-quote that prevails 15 minutes after trade execution. PrcImp is defined as $q_t \times (m_{t+\Delta}^{\text{D2D}} - m_t^{\text{D2D}})$. Both transaction prices and quotes are in terms of par spreads and expressed in basis points. Trade direction, q_t, is inferred by the Lee and Ready (1991) algorithm. Rejection of a regression-based t-test for the null hypothesis that sample means are identical to those of trades in the limit order book at the 1% and 5% level is denoted by ** and *, respectively, with inference based on the Newey and West (1987) estimate of the covariance matrix of coefficient estimates. The sample period is October 2, 2013 to October 16, 2015 and comprises 1,333 (1,290) [3,782] {470} and 1,124 (1,172) [4,473] {456} outright trades in the limit order book (workups) [mid-market matches] {trades with unidentified trading protocol} in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively.

	CDX.IG	CDX.HY
Mean	0.229	1.291
Standard deviation	0.168	0.838
25th	0.166	0.924
Median	0.235	1.317
75th	0.307	1.645
% price improvement > 0	95.8	96.4
% within bid-offer spread	95.3	96.1

Table 7: Price Improvements of Dealer-to-Client Trades.

The table shows descriptive statistics of price improvements for outright dealer-to-client (D2C) trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY. Price improvements are with respect to inside quotes on the limit order book of the GFI Swaps Exchange. Price improvement is defined as $o_t^{\text{D2D}} - p_t$ if $q_t = 1$ and $p_t - b_t^{\text{D2D}}$ if $q_t = -1$, where p_t is the transaction price and b_t^{D2D} and o_t^{D2D} are the latest GFI bid and offer quotes, respectively, in the 15-minute period prior to trade execution. Both transaction prices and bid and offer quotes are in terms of par spreads and expressed in basis points. Trade direction, q_t, is inferred by the Lee and Ready (1991) algorithm. The sample period is October 2, 2013 to October 16, 2015 and comprises 49,425 and 70,628 outright D2C trades in five-year on-the-run index CDSs on CDX.IG and CDX.HY, respectively.