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**Financial Oligopolies: Theory and Empirical Evidence
in the Credit Default Swap Markets**

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FINANCIAL OLIGOPOLIES: THEORY AND EMPIRICAL EVIDENCE IN THE CREDIT DEFAULT SWAP MARKETS

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Abstract

On the basis of the documented oligopolistic structure of the CDS and Loan CDS markets, we formulate a Cournot-type oligopoly market equilibrium model on the dealer side in both markets. We also identify significantly positive and persistent earnings from a simulated portfolio of a very large number of matured contracts in the two markets with otherwise identical characteristics, which are robust in the presence of trading costs. The oligopoly model predicts that such profitable portfolios are consistent with the oligopoly equilibrium solution and cannot be explained by alternative absence or limits of arbitrage theories.

Keywords: Credit Default Swap, Loan Credit Default Swap, Market Efficiency, Market Segmentation, Market Power

JEL Classification: G3, G14, G18, G32

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1. INTRODUCTION

Credit Default Swaps (CDS) and Loan CDS (LCDS) contracts are essentially financial agreements between protection buyers and protection sellers to transfer the credit risk of the underlying assets (respectively, corporate debts and syndicated secured loans). The more recent LCDS market has grown quickly since the introduction of the ABX index in 2006, fueled by the rapid growth in its underlying asset markets. Compared to traditional CDS contracts, LCDS contracts have higher recovery rates and cancellability options. Unlike the CDS market, the LCDS market has not been studied as extensively in the financial literature.

In this paper we formulate a Cournot-style oligopoly model of simultaneous trading in the CDS and LCDS markets, motivated by recent evidence of the highly concentrated nature of such markets. We also document positive and persistent profits from portfolios taking opposite positions in two different CDS contracts on the same reference entity. These profits are confirmed ex post with a very large sample of matured contracts. Our oligopoly model predicts that the observed profitable portfolios arise as a consequence of the oligopolistic equilibrium and will persist as long as there are barriers to entry in the two markets. We extend the model to include trading costs and show that such costs are barriers to small-scale entry that can be overcome by the traders' increasing start-up capital as a form of economies of scale. We show that the profitable portfolios disappear only when the number of oligopolists tends to infinity, consistent with competitive equilibrium. We use a novel data set and examine empirically the contrasting predictions of the oligopoly models with the competing limits to arbitrage theory and show that the evidence overwhelmingly favors the former. To our knowledge, this is the first empirical paper to apply industrial organization (IO) modeling principles to the study of financial derivatives markets.

The competitive equilibrium limit of our oligopoly also is found to correspond to the same pricing-parity relation as the no arbitrage equilibrium model. This relation between CDS and non-cancellable

LCDS contracts written on the same firm with the same maturity and restructure clauses also involves the recovery rate estimates for both types of contracts contained in our data set.

¹ It assumes no uncertainty of these recovery rate estimates in the event of default but is otherwise model-free. Using single name CDS and LCDS daily observations on 1-, 3- and 5-year contracts during the period from April 2008 to March 2012 from datasets provided by the Markit company, we document time-varying and significantly positive current payoffs on a simulated portfolio that exploits the observed pricing-parity deviations by simultaneously taking the appropriate positions in the corresponding markets.² For the observed CDS and LCDS spreads and the reported recovery rates in the case of default for both types of contracts,³ the current payoffs to these portfolios are persistently positive over most of our time series data even after including a generous allowance for transaction costs.⁴

We apply our portfolios designed to exploit the pricing parity deviations to the subsample of one- and three-year maturity contracts that have expired within our data period. There were more than 18,000 such CDS-LCDS contract pairs with pricing parity deviations within the period April 2010-March 2011, after the financial crisis, in our data set. *All of them* showed positive cash flows even after a generous allowance for transaction costs, with an average size that is far too large to be justifiable by counterparty risk, which anyhow did not materialize anywhere ex post. With such a large sample there is also a virtually zero probability that the payoffs for longer maturities are rewards for risk due to the unreliability of the recovery rates reported in the databases as estimates of the “true” recovery rates upon default, given that the same portfolio selection rules were used in all cases. If our simulated strategies had actually been applied to these matured contracts at the average notional contract size of \$5 million they would have generated total profits of more than \$6.9 billion dollars in total. Thus, although the portfolio payoffs are

¹ See Dobranszky (2008) and Ong, Li and Lu (2012) for the discussion of CDS and non-cancellable LCDS parity.

² The current pricing-parity deviation should be zero under the no arbitrage and no recovery rate uncertainty assumptions. Deviations from parity imply that we observe positive current payoffs on the simulated portfolio.

³ We also call them “Estimated Recovery Rates” since these recovery rates are estimated and provided to Markit by its clients who are active participants in these markets and generally are large financial institutions.

⁴ Note that this anomaly is emphatically not related to the financial crisis, since it appears throughout the entire period of our data, unlike the violations of arbitrage relations between the CDS and underlying bond markets documented by Alexopoulou, Andersson and Georgescu (2009) and Bai and Collin-Dufresne (2013).

not arbitrage profits in the strict sense of the word due to the recovery rate uncertainty and margin requirements, they correspond to arbitrage in the statistical sense, since the probability of loss is statistically insignificant.

Motivated by the fact that the number of traders providing quotes in both markets at any point in time in our data set is small, and by several recent studies documenting the highly concentrated nature of the CDS markets, we develop an oligopoly model of simultaneous trading in the CDS and LCDS markets. We consider three different types of agents, those who trade exclusively in only one of the two markets, CDS and LCDS, and a third type, dealers or arbitrageurs, who trade in both. We show that in such a setting pricing parity *would not hold* in equilibrium. In fact, the parity relation requires a perfectly competitive dealer market for both contracts, while in imperfectly competitive markets it is modified by the two individual markets' elasticity ratios. We also show that oligopolists act as arbitrageurs by taking opposite positions in the two markets. We extend the model to allow for trading costs and different prices for long and short positions in both markets and show that the conclusions of the frictionless market hold in a modified form that includes a no trading zone. In fact, trading costs act as a barrier to entry of "small" firms and the oligopoly becomes a case of competition among the big and the small, as in recent IO studies.⁵

In our empirical work, using the number of traders providing quotes in the two markets as a proxy for the relative level of competition, we find trading profits consistent with this elasticity-modified parity ratio. We also test formally the market power hypothesis against the alternative of limits to arbitrage theory. In the former case the observed parity violations are normal outcomes of oligopolistic market equilibrium, while in the latter they are anomalous and will tend to disappear. In our tests we find no evidence of long run convergence towards the parity relation to justify the slow moving capital conjecture as an impediment to arbitrage. In fact, the market seems to react to the absence, rather than the presence of parity violations, as predicted by our oligopoly model. Most importantly, the duration of the observed profits in any given pair of CDS-LCDS contracts is strongly positively associated with the size of the

⁵ See, for instance, Shimomura and Thisse (2012).

profits, consistent with a non-competitive market structure and exactly the opposite of what would be expected under limits to arbitrage. We conclude that market structure is the most likely explanation for this apparent trading anomaly.⁶

To our knowledge, this paper is the first to document such anomalous portfolios within credit derivative markets and to link them specifically to the markets' non-competitive structure.⁷ Our paper contributes to the growing literature on integrated studies of stock, bond, option and CDS markets and to the more recent studies of the interaction between corporate finance and industrial organization. Earlier studies have focused on information flows between the various markets but have not uncovered any tradable anomalies that do not involve privileged information.⁸ Our results, based on one of the most popular data sources for credit derivatives, also raise questions on the appropriateness of deriving financial asset prices based on frictionless competitive equilibrium among different markets without examining whether the competitive nature of these markets is, in fact, supported by the data.

The consequences of our oligopolistic market structure model are relatively easy to study empirically in our case because if both CDS and LCDS contracts are written on the same firm the claims are triggered by the same default events which are defined by the International Swap and Derivatives Association (ISDA). Thus, the default and survival probabilities of these credit derivatives should be exactly the same given the same maturities, restructuring clauses and denominated currencies. However, the syndicated secured loans, the underlying assets of the LCDS, generally have higher priority during the bankruptcy process compared to senior unsecured debts which are the underlying assets of CDS. The derived market equilibrium condition implies absence of profitable portfolios only under competitive conditions in the

⁶ A third possibility suggested by some discussants in earlier versions of this paper, is that the Markit data is not representative of actual trading conditions. Such an explanation would nullify just about every empirical CDS study (many of which have been published in top tier journals), since most of them have used the same data. Further, the Markit data is based on quotes, implying that it at least represents potential trades, which is all that is needed for an arbitrage.

⁷ Ong, Li and Liu (2012, p. 68) mention that the CDS and LCDS operate on “decidedly inconsistent markets” and present the pricing parity relation developed in the next section, but do not provide any evidence in support of their statement. Atkeson *et al* (2013) and Bolton and Oehmke (2013) focus on the market structure of credit derivatives but do not use any data in support of their arguments.

⁸ See, for example, Acharya and Johnson (2007) on insider trading in the CDS and stock markets, Berndt and Ostrovnaya (2008) on information revelation in option, CDS and equity markets, and similar information flow studies by Norden and Weber (2009) and Forte and Pena (2009).

dealer market, which are not supported by our data and are anyhow contradicted by recent studies documenting the highly concentrated nature of the CDS markets. We also verify independently the regulatory framework and entry conditions in CDS markets and document barriers to entry imposed by trading platforms on important traders that could have eliminated the profitable portfolios, and examine the role of margins in preventing small-scale entry.

We verify several other possible explanatory factors that support the alternative limits to arbitrage theory such as transaction costs, uncertainty of recovery rates, margins, contract illiquidity, slow moving capital or counterparty risk. In our robustness checks and online appendix we also examine the reliability of the Markit recovery rate data used in establishing the simulated portfolios, even though this is not a factor for the observed matured contract payoffs. We find that these data are in almost all cases unbiased estimates of the realized recovery rates reported in earlier studies and in Moody's database. We also confirm that our results are robust to recovery-rate concerns when we estimate the risk-adjusted default probabilities from the Leland and Toft (1996) structural model estimated using Generalized Method of Moments (GMM) and data from accounting reports and the equity and option markets. Our results are also robust with respect to the illiquidity concern, which is a key component of the oligopoly model. In our online appendix we document fewer positive deviations for the less liquid CDS and LCDS contracts with maturities other than five years and we show that an illiquidity factor cannot be extracted from a principal components analysis of the portfolio payoffs.

In the absence of detailed microstructure data that identifies the traders in both markets it is impossible to confirm with certainty that the observed payoffs of our arbitrage strategy are due to the non-competitive market structure. The motivation for our theoretical model of oligopoly on the dealer side arises from the fact that in our data a very small number of traders participate in the CDS and (especially) the LCDS markets and from several recent studies⁹ that document a very concentrated market structure in all CDS markets. In those markets a small number of very large financial institutions act as dealers, while

⁹ See Atkeson, Eisfeldt and Weill (2013, pp. 7-8), Peltonen, Scheicher and Vuillemeys (2014) and Duffie, Scheicher and Vuillemeys (2015).

middle-sized and small banks use CDS to hedge their credit exposures.¹⁰ More formally, the stylized general equilibrium model of the banking sector in the NBER study by Atkeson *et al* (2013) shows that the market concentration on the CDS dealer side arises under free entry equilibrium due to the differing sizes of the firms in the banking sector even in the absence of entry deterrence conduct. Thus the barriers to entry in the dealer market in the CDS-LCDS market pair may be due to economies of scale, again a well-known phenomenon in the IO literature.¹¹ In commenting on that study, Bolton and Oehmke (2013, p. 4) point out the possibility of collusion with such high concentration and cite anecdotal evidence of highly lucrative trading in that market. Further, Peltonen *et al* (2014) present data according to which in 2011 the 10 largest traders had a market share in excess of 70% in all CDS trading subnetworks. Last, market power evidence comes from an ongoing antitrust investigation of 13 major US and international financial institutions by the European Commission for anticompetitive agreements in the CDS markets, and from the many class action suits filed in the United States.¹² Our oligopoly model shows that collusion is not required in order to produce profits from intermarket arbitrage and suggests that the strategies identified in this paper may have already been realized by dealers executing them on their behalf to the available depth of counterparty traders. We discuss the regulatory implications of our findings in the last section of this paper.

Our study is not the first one to document absence of integration between markets for related financial instruments. In fact, the limits to arbitrage approach, introduced by the classic work of Shleifer and Vishny (1997), has spawned a significant volume of follow up literature, some of which is empirical and

¹⁰ Market power on the dealer side in the CDS market has also been documented by Gunduz, Nasev and Trapp (2013), who use microstructure data that identifies traders by type, and by Gupta and Sundaram (2013), who study CDS settlement auctions.

¹¹ This was first pointed out by Bain (1956). See also Perrakis and Warskett (1986).

¹² See the July 1, 2013 press statement of the Commission's Vice-President responsible for competition policy, available at http://europa.eu/rapid/press-release_SPEECH-13-593_en.htm. The first class action suit filed by the Sheet Metal Workers Local 33 Cleveland District Pension Plan against 12 financial institutions and two other entities "seeks "buy side" damages incurred in buying or selling CDS contracts to the "sell side" defendant dealers between 2008 and 2011, alleging that the defendants illegally coordinated to limit competition raising fund managers' costs" (<http://www.ipvancouverblog.com/2013/05/class-action-filed-in-credit-default-swap-cds-case/>). During October 2013, The US Judicial Panel on Multidistrict Litigation decided to centralize the cases alleging price-fixing in the market for credit default swaps for the purposes of pretrial proceedings in the District of New Jersey.

supportive of the theory.¹³ In most of this literature, however, the arbitrage relations are model-based and their failure may be due to model error. What makes our setup unique is the simplicity of the integration relationship and a model-free parity relation under various market structures, which is clearly not supported by the data in its competitive no arbitrage format, and the unequivocal confirmation of the ex post profits from the large sample of matured contracts. Our study is also the first to attribute and empirically support the lack of integration of the two instruments to imperfect competition.¹⁴

The rest of the paper is organized as follows. In Section 2 we briefly describe the CDS and LCDS markets, including the regulatory environment over the period of the study and the possible barriers to entry, and present the data and the method of sample selection for the empirical work. Section 3 develops the simultaneous equilibrium oligopoly market model with and without trading costs. In Section 4 we present the alternative no arbitrage equilibrium parity relation, which coincides with perfect competition in our oligopoly model, and construct the simulated portfolio strategy to exploit its violations. Section 5 contains our main empirical evidence in support of the oligopoly model, in the form of a large observed sample of simulated portfolios with current payoffs (pricing-parity deviations) given transaction costs. We also discuss other possible reasons apart from oligopoly for the positive payoffs; namely, reward for risk and limits to arbitrage, and find no support that the payoffs are a reward for bearing risk. Section 6 presents further direct tests of the competing oligopoly market hypothesis over the alternative limits to arbitrage. Section 7 presents empirical evidence as robustness checks for other limits-to-arbitrage such as recovery-rate uncertainty, counterparty risk, contract illiquidity and convergence to parity. Section 8 concludes.

¹³See Deville and Riva (2007), Brav, Heaton and Li (2010), Gârleanu and Pedersen (2011), Lam and Wei (2011), Kapadia and Pu (2012), Bhanot and Guo (2012), Mitchell and Pulvino (2012), Acharya *et al* (2013), and Hanson and Sunderam (2014). We found few empirical studies of limits to arbitrage in economic journals, although there is awareness of the concept in several theoretical studies; see Stein (2005), Thompson (2010), and Lee and Mas (2012). One such empirical study finds that funds experiencing withdrawals trade in a manner that exacerbates mispricing and that mispricing can persist for months (Mitchell, Pedersen, and Pulvino, 2007).

¹⁴ In fact the empirical literature on anticompetitive behavior in financial markets is rather limited and almost exclusively concentrated on stock trading; see the comments in Allen *et al* (2006, p. 646). The market segmentation in the Canadian option markets documented in Khoury, Perrakis and Savor (2011) was due to an exchange-mandated monopoly at the specialist level.

2. CDS AND LCDS MARKETS

2.1 CDS and LCDS Market Overview

The CDS market has existed for a long time but the LCDS market is relatively new and was launched in 2006 in both the US and Europe.¹⁵ It has grown very quickly since its inception because of the rapid growth in the underlying asset, itself driven by a surge in leveraged buy-outs, and also because of the introduction of industry-wide documentation published by the International Derivative and Swap Association (ISDA) to standardize and regulate the LCDS contract. While the reference obligations of CDS contracts are usually corporate debts, the reference obligations of LCDS contracts are syndicated secured loans. The LCDS contracts can be divided into Cancellable LCDS (European LCDS) and non-cancellable LCDS (US LCDS) contracts.¹⁶ In this study we concentrate on the US LCDS contract, which is designed as a trading product that can be used to generate marginal profits by creating a synthetic credit position where one commits to make (receive) payment in the case of default.¹⁷

Similar to an ordinary swap contract, there are physical and cash settlements for both CDS and LCDS contracts once the settlement is triggered by a credit event. The default settlement mechanism for European and US LCDS is physical settlement under which the protection seller pays an amount equal to the notional amount of the reference obligation covered by the LCDS multiplied by the reference price which is usually 100%.¹⁸ Under cash settlement, there is no delivery of the reference obligation and the protection seller only pays to the protection buyer the difference between par value and the market price after a credit event. Especially after the financial crisis, cash settlement has become more popular because the physical delivery of a loan is cumbersome and time consuming. In the cash settlement of a LCDS contract, the final price of the underlying syndicated loan is determined by an auction methodology.¹⁹

¹⁵ See Merrill Lynch (2007) and Bartlam and Artmann (2006). The template forms of LCDS documentation were published by International Derivative and Swap Association (ISDA) for the US and European LCDS market on 8th, June 2006 and 2nd, May 2006, respectively.

¹⁶ See Shek, Shunichiro and Zhen (2007) and Liang and Zhou (2010) for the valuation of cancellable LCDS.

¹⁷ Minton, Stulz and Williamson (2009) find that the use of credit derivatives by US banks is very limited and most of the credit derivatives are held for dealer activities rather than for the hedging of loans.

¹⁸ See Bartlam and Artmann (2006), page 5.

¹⁹ See the link: <http://www.creditfixings.com/CreditEventAuctions/fixings.jsp> for the details of CDS Auctions.

Short selling constraints are always a major concern when executing trading strategies for traditional investment instruments, especially for parallel trading in the corporate bond market. CDS and LCDS are essentially swap agreements between two counterparties to transfer the exposure to the default risk of the underlying asset. Thus, there is no requirement to hold the underlying assets,²⁰ especially under cash settlement, which makes an arbitrage position feasible.²¹ In the following analysis, we assume cash settlement for both CDS and LCDS contracts.

2.2 Regulation and Barriers to Entry

Since our data covers totally the financial crisis and partially overlaps with the ongoing regulatory reform of the Dodd-Frank Act, our empirical results took place under differing regulatory regimes. Over the period examined herein, CDS contracts have become more standardized, and electronic processing and central clearing of trades have increased but bilateral trades have apparently continued throughout the entire period. Regulatory approvals by the Securities and Exchanges Commission (SEC) dealing with margin requirements include an interim pilot program for dealer members of the Financial Industry Regulatory Authority (FINRA) in 2009 (Rule 4240) which was further extended, for example, in 2011. To increase transparency and reduce systemic risk, a central clearing corporation (CCP) was introduced by several trading platforms during the period to clear standard contracts. The first was the Intercontinental Exchange (ICE) in March 2009.

Under central clearing there is an intermediary between long and short positions that reduces counterparty risk by guaranteeing the execution of the swap agreements by monitoring the positions and market exposure of each clearing member to ensure that sufficient funds are on deposit to cover each member's risks. Institutions wishing to participate as dealers on the CCP can become CCP members provided that they have an A credit rating and a net worth of at least \$5 billion. In other words, there are clear scale effects in potential entry into the dealer function, especially given the fact that the A credit rating would rule out most hedge funds. Note that the evidence presented in the NBER study by Atkeson

²⁰ This is the so-called "naked" or "synthetic" contract.

²¹ See Mengle (2007).

et al (2013, Figure 2) shows that as of the end of 2011 only 12 of the largest bank holding companies trading in derivatives had trading assets in excess of that amount.

These entry restrictions are probably responsible for the undeniable fact of high concentration in the CDS market, let alone the dealer function, documented in several studies. Thus, in addition to the aforementioned NBER study a recent paper notes that in 2011 the 10 largest traders had a market share in excess of 70% in all CDS trading subnetworks. The authors also state (p. 119) that the CDS market "...is highly concentrated around 14 dealers, who are the only members of central counterparties...".²² Concerning the role of margins as barriers to entry, we note that traders are allowed to net out their margin positions, with the result that in 2011 the collateral to gross notional ratio in CDS trades was 0.78%, far below the ICE margins.²³ This netting out tends to favor large market participants who can hold multiple positions and who also enjoy the benefits of greater holding diversification. In our robustness checks we examine the role of margins for the matured one-year contracts using the ICE margins under the most adverse conditions.

In conclusion, therefore, the evidence on the institutional environment faced by those willing to trade in the CDS-LCDS market pair is that, although there are no formal regulatory barriers, there is high concentration of trading and serious restrictions to entry into the dealer function in both markets. This, in turn, motivates our oligopoly model to study intermarket arbitrage.

2.3 Sample and Data for the Empirical Work

For the empirical part of this paper we obtain our CDS and LCDS data from Markit who collects the quotes on LCDS spreads from large financial institutions and other high quality data sources and produces the LCDS spread database on a daily basis starting from April 11, 2008. Our sample is from April 11th, 2008 to March 30th, 2012, which encompasses the credit crisis and the accompanying recession. We only use US (non-cancellable) LCDS to construct the portfolios. As a robustness check on

²² See Peltonen, Scheicher and Vuillemeay (2014, p. 119).

²³ See Duffie, Scheicher and Vuillemeay (2015).

the size of the transaction costs, we also match part of our CDS sample to intraday quote data also provided by Markit in a separate data base.

In the CDS market we select the contracts on senior unsecured debts since this type of contract is the most liquid and is used frequently in the literature. In the LCDS market, we select the contracts on the first-lien syndicated loans since the claims on collateral for the first-lien loans are senior to those of the second-lien loans, which indicate more reliable estimated recovery rates for these loans. In addition, the LCDS contracts on first-lien loans form the majority in our data source and are more liquid than those on the second-lien loans. We restrict our CDS and LCDS contracts to those in the United States and denominated in US dollars. To ensure that the first-passage default and survival probabilities of the CDS contracts are exactly the same as those of the corresponding LCDS, we match the daily LCDS and CDS data based on company name, denominated currency, restructure clauses and time to maturity. We focus on the contracts with a 5-year maturity since they are the most liquid contracts and the most studied in the previous literature.²⁴ We also study in some detail the 1-year and 3-year maturities, since they contain many matured contracts within our data set. The contracts with 7-year and 10-year maturities are studied as robustness checks.

A key component of any CDS market model is the recovery rate upon default. To proxy for the unobservable real recovery rates we use the estimated recovery rates extracted from our Markit datasets, which are based on the raw data providers' estimates.²⁵ These recovery rate expectations at time of issue may differ from subsequent recovery-rate expectations and actual recovery rates.²⁶ Nevertheless, these Markit estimates represent the only available proxy for the real recovery rates²⁷ and have been used repeatedly in previous studies.²⁸

²⁴ See Jorion and Zhang (2009), Cao, Yu and Zhong (2010, 2011), Schweikhard and Tsesmelidakis (2012), Qiu and Yu (2012) and Zhang, Zhou and Zhu (2009).

²⁵ Based on Markit CDS and Bonds User Guide, their clients can also contribute their recovery rates. Data on recovery rates are denoted throughout the Markit product as Client Recovery.

²⁶ Jokivuolle and Peura (2003), Altman, Brady, Resti and Sironi (2005), Hu and Perraudin (2002) and Chava, Stefanescu and Turnbull (2006) report that the recovery and default rates are negatively correlated.

²⁷ The real recovery rates are collected from Moody's Default and Recovery Database and discussed in Section 4.

²⁸ See Huang and Zhu (2008), Zhang, Zhou and Zhu (2008), and Elkamhi, Ericsson and Jiang (2012). Loon and Zhong (2014, pp. 112-113) give a detailed description of the Markit data collection procedures.

2.4 Data Description

[Insert Table 1 about here]

Table 1 reports the summary statistics for our full sample and the sub-samples classified by credit rating. We eliminate the observations whose CDS spreads (or LCDS spreads) are greater than 1 and the single name contracts which have less than 120 consecutive daily observations. In addition, we obtain the accounting variables from COMPUSTAT, economic macro variables from Federal Reserve H.15 database and equity trading information from CRSP. After merging all these datasets and removing the missing observations and private firms, the full sample contains 68,147 firm-clause-daily cross-sectional observations for 120 single names during the sample period from April 11, 2008 to March 30, 2012.

In the full sample, the mean LCDS and CDS spreads are around 3.7% and 4.6%, respectively. Both medians are smaller than their corresponding means which indicate asymmetric distributions and fat tails, especially on the right side. These style factors are also verified by positive skewness for the CDS and LCDS spreads. The distributions of recovery rates estimates for the LCDS and CDS contracts are close to a Gaussian distribution with slightly negative skewness. Both the mean and median of the LCDS recovery rates, around 65% and 70% respectively, are greater than the corresponding statistics for the CDS contracts, around 38% and 40% respectively. The syndicated secured loans (the underlying assets of LCDS) are usually backed up with collateral and have claim priority compared to the senior unsecured debts which are the underlying assets that back the CDS once the default event occurs.²⁹ The sub-sample of investment grades (includes firms rated greater than or equal to BBB), accounts for more than 60% of the total observations, while junk-rated contracts and not rated contracts share almost equally the rest of the observations, approximately 20% each. As expected, both the mean and median of the CDS and LCDS spreads in the investment grade sub-sample are relatively lower compared to the junk and not rated sub-samples, while the mean and median of the recovery rates are broadly similar in all three sub-samples. There are also differences in the accounting variables among the sub-samples, with the junk

²⁹ This implies that the LCDS recovery rate estimates should exceed the corresponding CDS ones. This turns out to be true for all but 265 out of the 68,147 pairs of data points. For more on the priority of the LCDS claims see Section 5.5.

firms being smaller and more heavily indebted than the investments grade firms. The not-rated firms are mostly relatively small firms in terms of their total assets, with diverse accounting ratios.

We observe extremely high first-order autocorrelations in the daily spreads for CDS (around 0.98) and LCDS (around 0.97) indicating a spread clustering effect in both markets. The first-order autocorrelation of LCDS recovery rates of approximately 0.93 is much higher than that for CDS recovery rates of around 0.77. This further supports the conjecture that LCDS recovery rates are more persistent and reliable compared to their counterparts for CDS contracts. If we lower the frequency of the data from daily to quarterly, the first-order autocorrelations decrease significantly for all the variables.

The daily idiosyncratic volatilities³⁰ of the full sample have a mean around 2.4% with positive skewness and extremely high kurtosis. As expected, both the mean and median of daily idiosyncratic volatilities of the investment grade firms are relatively lower than those of junk-rated firms. For the not rated firms, the daily idiosyncratic volatilities are more volatile compared to the other sub-samples.

3. AN OLIGOPOLY EQUILIBRIUM MODEL OF CDS AND LCDS MARKETS

3.1 The Structure of the CDS and LCDS Markets: Further Evidence

In most of the financial literature the valuation of CDS and LCDS contracts is normally done by a no arbitrage methodology and by assuming that the values of the two cash flows involved in a swap are equal. An additional implicit assumption is that the markets are perfect and competitive. As we discussed in the previous sections, the available evidence does not support this assumption, which is further examined in this subsection on the basis of our dataset.

We assess the imperfectly competitive structure of both markets from the number of distinct dealers providing daily quotes on the 5-year CDS and LCDS contracts as reported in the Markit data base.³¹ In the full sample there are on average 5 and 1.6 dealers quoting on the same firm's CDS and LCDS

³⁰ The calculation details are provided in Section 6.

³¹ Qiu and Yu (2012) use the same liquidity measure to study the liquidity in the single-name credit default swap market. This is consistent with the theoretical model of Grossman and Miller (1988) that explains the relation between liquidity and the number of market makers given no barriers or stickiness to entry. With regard to entry stickiness, the second critical assumption in the modeling of a run on a financial market by Bernardo and Welch (2004) is that the market making sector is risk-averse in the aggregate and cannot expand infinitely in an instant.

contract, respectively, demonstrating the relatively higher dealer participation and liquidity of the CDS compared to the corresponding LCDS contracts. As the rating decreases from investment to junk grade, we document a significant decrease of CDS liquidity, from 5.92 to 4.96, and a slight decrease of LCDS liquidity, from 1.67 to 1.64, on average. In the not rated sub-sample the liquidity of CDS contracts is reduced even further and all of them have the same average number of dealers, two. On the other hand, the liquidity of the LCDS contracts moves in the opposite direction, increasing to 1.88 on average, higher than in the rated contracts.

Our data, therefore, shows a strongly concentrated structure at the dealer level. To see its consequences we model the simultaneous market equilibrium in both markets assuming initially the absence of frictions and an oligopoly at the dealer level. Our simplified model abstracts from some realistic market features but is quite general in its assumptions and retains the necessary elements for the equilibrium analysis. It also contains the competitive and monopoly structures as limit cases.

3.2 A Frictionless Cournot Oligopoly at the Dealer Level

For every single firm on which CDS and LCDS contracts are traded we distinguish three categories of agents and two markets denoted by the subscript $i = 1, 2$ for the CDS and LCDS respectively. In each market c_i and R_i , $i = 1, 2$, denote the corresponding premium and recovery rate estimate contained in the database. Two classes of agents are assumed to trade exclusively in each one of the two markets for insurance or speculative purposes, who may or may not hold the firm's bonds and credit lines, respectively.

We do not model the behavior of these two groups but represent each group's joint decisions by the function $C_D^i(c_i)$, $i = 1, 2$, the *net* demand volume of contracts (long minus short, or the conventional demand curve minus the conventional supply curve in the corresponding market) in markets $i = 1, 2$, a decreasing function that becomes negative for sufficiently high values of the c_i 's indicating net short positions. For reference purposes we also consider the *equilibrium* premiums, which equalize the traded

volume of contracts for each group of agents, and are denoted by \hat{c}_i , $i=1,2$. It is assumed that the demand functions are exogenous, and that the marginal revenues $\frac{d[c_i C_D^i(c_i)]}{dc_i}$, $i=1,2$ increase as the prices increase or the quantities decrease, the usual assumptions for oligopoly equilibrium. The agents' net positions are negative (positive) whenever $\hat{c}_i \leq c_i$ ($\hat{c}_i \geq c_i$). $1-R_2$ and $1-R_1$ denote the expected losses in the LCDS and CDS contracts, respectively, in the event of default. Recognition of the priority rule implies $1-R_2 < 1-R_1$.³²

We model explicitly the decisions of the third category of traders in the two markets, the $J \geq 1$ traders termed arbitrageurs or dealers, who trade simultaneously in both markets and provide the residual liquidity to clear the markets. We consider a two-period horizon (0 and 1), with the terminal date corresponding to the maturity of the contracts. Let Y_i , $i=1,2$ denote the arbitrageurs' net demand in the two markets at contract maturity, for which we must have the clearing condition, omitting the time subscript:

$$C_D^i(c_i) + Y_i = 0, \quad i=1,2 \quad (3.1)$$

Each arbitrageur $j=1, \dots, J$, $J \in [1, \infty]$ is assumed to choose her demand y_i^j , $\sum_j y_i^j = Y_i$, $i=1,2$

by maximizing the expected utility of a function $U^j(W_1^j)$ of discounted terminal wealth W_1^j at the maturity of the contracts. Apart from concavity and decreasing absolute risk aversion (DARA), we do not impose any other restrictions on the utility functions, nor do we assume that they belong to the same family.³³ Since the product is homogenous in both markets, in the absence of collusion the joint

³² The recovery rates represent expectations at contract time given default within the contract period, conditional on asset value or possible macroeconomic variables; they need not be assumed constant. In the financial literature's structural models of the firm the losses given default are non-increasing functions of the unlevered asset value.

³³ Several theoretical studies on arbitrage assume that the utilities of all investors belong to the Constant Absolute Risk Aversion (CARA) type, $\exp(-\alpha^j W_1^j)$; see for instance Gromb and Vayanos (2002, 2010) and Fardeau (2012, 2014). While such a formulation simplifies the equilibrium expressions, our important results do not need it for their proofs.

equilibrium is a Cournot oligopoly, with each arbitrageur choosing y_i^j by the maximization of expected utility, with τ denoting the random default time and $P^S(\tau)$, $P^D(\tau)$, the corresponding probabilities of survival and default within the contract horizon T

$$\begin{aligned} & \text{Max}_{y_1^j, y_2^j} \{E[U^j(W_1^j)]\} \\ & = \text{Max}_{y_1^j, y_2^j} \left\{ \int_0^T P^S(\tau) U^j(W_1^j(\tau)|S) d\tau + \int_0^T P^D(\tau) U^j(W_1^j(\tau)|D) d\tau \right\} \\ & \quad j = 1, \dots, J \end{aligned} \quad (3.2)$$

In this maximization all $y_i^k, k \neq j$ are taken as given, $\sum_j y_i^j = Y_i$, $i = 1, 2$, as per the market equilibrium condition (3.1), and the wealth constraint (3.3) holds, with W_0^j denoting the initial wealth³⁴ and with $W_1^j(\tau)$ given by

$$\begin{aligned} W_1^j &= W_0^j + e^{-r\tau} \{y_1^j[(1-R_1)-c_1] + y_2^j[(1-R_2)-c_2]\} \equiv W_1^j(\tau)|D, \text{ if default at } \tau \in [0, T] \\ W_1^j &= W_0^j - \{y_1^j c_1 + y_2^j c_2\} e^{-r\tau} \equiv W_1^j(\tau)|S, \text{ if no default (survival) for all } \tau \in [0, T] \end{aligned} \quad (3.3)$$

To evaluate the expectation in (3.2) the utility of terminal wealth is weighted by the default and survival probabilities. It is integrated over the entire contract length, representing the discount factors and the probabilities of default and survival respectively at any time during contract duration.

The maximization of the objective function (3.2) yields the following first order conditions (FOC) for the joint equilibrium

$$\begin{aligned} & \frac{(1-R_i) \int_0^T P^D(\tau) U^j(W_1^j(\tau)|D) d\tau}{\int_0^T P^S(\tau) U^j(W_1^j(\tau)|S) d\tau + \int_0^T P^D(\tau) U^j(W_1^j(\tau)|D) d\tau} = c_i \left(1 + \frac{y_i^j}{Y_i \varepsilon_D^i}\right) \\ & \sum_1^j y_i^j = -C_D^i(c_i), \quad i = 1, 2 \end{aligned} \quad (3.4)$$

³⁴ Since the dealers are assumed, following Shleifer and Vishny (1997), to be “highly specialized investors using other people’s capital”, the initial wealth is a proxy for economies of scale at the dealer level and will be shown to play an important role on entry further in this section. They also represent the capacity to cover required margins.

Where $U^j(W_1^j(\tau)|D)$ and $U^j(W_1^j(\tau)|S)$ denote the marginal utilities of the j^{th} arbitrageur under firm default and survival respectively, and $\varepsilon_D^i(c_i) = \frac{c_i C_D^i}{C_D^i}$, $C_D^i \equiv \frac{\partial C_D^i}{\partial c_i}$, $i=1,2$ denote the price elasticity of demand in each market.

Dividing the two relations in (3.4) with each other, we get the following result

$$\frac{c_1(1 + \frac{y_1^j}{Y_1 \varepsilon_D^1})}{c_2(1 + \frac{y_2^j}{Y_2 \varepsilon_D^2})} = \frac{1 - R_1}{1 - R_2} \quad (3.5)$$

Let now

$$\frac{\int_0^T P^D(\tau) U^j(W_1(\tau)|D) d\tau}{\int_0^T P^S(\tau) U^j(W_1(\tau)|S) d\tau + \int_0^T P^D(\tau) U^j(W_1(\tau)|D) d\tau} \equiv \Psi^*(j), \quad \bar{\Psi}^* \equiv \frac{1}{J} \sum_j \Psi^*(j) \quad (3.6)$$

denote, respectively, the common factor in the two equations of (3.4) evaluated at the optimal number of contracts and its summation over j . Aggregating equations in (3.4) and dividing by J on both sides, we eliminate the market shares from (3.4) and obtain the equilibrium relations for the average dealer participating in the two markets:

$$(1 - R_i) \bar{\Psi}^* = c_i \left(1 + \frac{1}{J \varepsilon_D^i}\right), \quad i = 1, 2. \quad (3.7)$$

Observe also that relations (3.4) and (3.7), although they are the outcome of a Cournot-style oligopoly equilibrium, are in fact consistent with the conventional valuation relations of asset pricing theory, defined in footnote 40 in the following section. Indeed, the left-hand-side (LHS) of both relations is the expected cost of default in the two markets in the risk neutral world, where the default probabilities have been weighed by the arbitrageurs' marginal utilities, individually and as a market aggregate respectively. These risk-adjusted costs are equated to the individual and aggregate marginal revenues.

Taking the ratio, we get the following result,

$$\frac{c_1(1 + \frac{1}{J\epsilon_D^1})}{c_2(1 + \frac{1}{J\epsilon_D^2})} = \frac{1-R_1}{1-R_2} \quad (3.8)$$

In line with standard results for the Cournot game, we note that relation (3.8) contains as special cases both the competitive case for $J \rightarrow \infty$, when the elasticity effect disappears, and the monopoly case for $J = 1$. In the following section we show that the competitive case is a more general version of a valuation relation under no arbitrage assumptions in the absence of transaction costs. Such a relation emerges as a special case of the oligopoly equilibrium if the recovery rates are constant under competitive conditions in the dealer market (infinitely many arbitrageurs and no minimum scale restrictions), where each arbitrageur maximizes (3.2) with respect to y_i^j , $i = 1, 2$, given c_1 and c_2 . In the absence of competition each contract premium must be modified by the elasticity and the number of dealers. In other words, if the

observed ratio $\frac{c_1}{c_2} \neq \frac{1-R_1}{1-R_2}$, it may be either because there is mispricing or because there is imperfect

competition and market power at the dealer level. In the former case we expect changes over time would converge to the “correct” ratio (slow moving capital). In the latter case no such convergence is to be expected, since (3.8) holds and the equilibrium ratio also depends on the demand elasticities and the number of Cournot dealers. In our model J is common to both markets, since the arbitrageurs provide liquidity to both markets. Nonetheless, the two-market Cournot equilibrium is entirely consistent with our data, in which one market (the CDS) has a larger number of traders than the other. Those traders participating in only one of the two markets are absorbed by the market demand curve.

3.3 Properties of the Frictionless Cournot Equilibrium

An arbitrage between the CDS and LCDS markets is defined as an equilibrium in which y_1^j and y_2^j have different signs in the Cournot equilibrium relations (3.4) for every dealer. The following result, proven in the appendix, shows that this equilibrium does, indeed, correspond to an arbitrage.

Proposition 1: *If y_1^{j*} and y_2^{j*} denote the optimal quantities for the j^{th} Cournot player then their signs are opposite and the oligopolist acts as an arbitrageur between the two markets.*

Proposition 1 implies that each Cournot player participates in opposite sides in the two markets and $\text{sign}(y_1^j y_2^j) < 0$, for all j , or that arbitrage trading is part and parcel of market equilibrium in the oligopoly structure. Furthermore, such trading is not the result of collusion or otherwise non-competitive behavior but appears as an optimal strategy in a competitive oligopoly game. This conclusion has certain empirical implications that are explored in subsequent sections.

The following result can also be shown for the Cournot equilibrium in all cases and for all players.

Proposition 2: *If y_i^{j*} and y_i^{k*} , $i = 1, 2$ denote the optimal contracts for two different Cournot players, then $y_1^{j*} \geq y_i^{k*}$ implies $y_2^{j*} \leq y_2^{k*}$ and vice versa.*

Proposition 2 implies that, if $y_1^{1*} \geq \dots \geq y_i^{J*}$, then $y_2^{1*} \leq \dots \leq y_2^{J*}$. In other words there is a scale effect, with a large market share in one market implying also a similarly large market share of an opposite sign in the other market. Observe that these inequalities do not necessarily imply that all Cournot players adopt the same arbitrage strategy. Indeed, suppose that $Y_1 > 0$ and $Y_2 < 0$. Then appendix relation (A.2) implies that, if $y_1^{1*} \geq \dots \geq y_i^{J*}$ we must also have $\Psi^*(1) \leq \dots \leq \Psi^*(J)$, but while necessarily $y_1^{1*} > 0$ and $y_2^{1*} < 0$, we may still have $y_1^{J*} < 0$ and $y_2^{J*} > 0$ beyond some value of J^* .

3.4 Cournot Equilibrium Under Trading Costs

Let again $C_D^i(c_i)$, $i = 1, 2$ denote the *net* demand volume of CDS contracts in the frictionless economy, and k_i , $i = 1, 2$ the trading costs. We assume that for any CDS-LCDS contract pair these costs are platform-wide and exogenously determined, applicable to all such pairs. In other words, our dealer oligopoly determines jointly the trading costs for the platform, but lets the dealers compete as Cournot players in each contract pair. By definition, at the competitive frictionless equilibrium premiums \hat{c}_i , $i = 1, 2$ we have $C_D^i(\hat{c}_i) = 0$, $i = 1, 2$.

The demand curves in the presence of trading costs become discontinuous, lowering (raising) the positive (negative) quantity segment by k_i , $i = 1, 2$. Instead of equation (3.1) we now have

$$\begin{cases} C_D^i(c_i - k_i) + Y_i \equiv C_D^{i-}(c_i) + Y_i = 0, & \text{if } C_D^i(c_i - k_i) > 0 \text{ (} Y_i < 0 \text{) for } c_i < \hat{c}_i - k_i, i = 1, 2 \\ C_D^i(c_i + k_i) + Y_i \equiv C_D^{i+}(c_i) + Y_i = 0, & \text{if } C_D^i(c_i) < 0 \text{ (} Y_i > 0 \text{) for } c_i > \hat{c}_i + k_i, i = 1, 2 \\ Y_i = 0, & \text{if } c_i \in [\hat{c}_i - k_i, \hat{c}_i + k_i] i = 1, 2 \end{cases} \quad (3.9)$$

In other words, the dealers provide the counterparty short (long) demand when the premium is sufficiently low (high), while they refrain from trading for the intermediate premium values.

The objective function, equations (3.2)-(3.3), remains the same, with the difference that now instead of c_i we have $c_i + k_i$ and $c_i - k_i$, $i = 1, 2$, depending on the sign of the corresponding y_i^j .³⁵ Adopting the innocuous assumption that all dealers trade in the same direction, it can also be easily shown that Proposition 1 also holds in the environment with frictions. In such a case we have, instead of (3.4) and setting + or – as superscript to the elasticity corresponding to the equivalent demand $C_D^{i+}(c_i)$ or $C_D^{i-}(c_i)$:

For a short position in CDS and long in LCDS we have

$$\begin{aligned} (1 - R_1)\Psi^*(j) &= (c_1 - k_1)\left(1 + \frac{y_1^j}{Y_1 \varepsilon_D^{1-}}\right) \\ (1 - R_2)\Psi^*(j) &= (c_2 + k_2)\left(1 + \frac{y_2^j}{Y_2 \varepsilon_D^{2+}}\right) \\ \sum_1^j y_1^j &= -C_D^{1-}(c_1), \quad \sum_1^j y_2^j = -C_D^{2+}(c_2) \end{aligned} \quad (3.10a)$$

Conversely, for a long position in CDS and short in LCDS we have

³⁵ The presence of trading costs raises questions of the existence of an arbitrage equilibrium as we defined in our oligopoly model, in the sense that none of the J dealers may find it profitable to trade in both markets. Since existence depends on the size of the trading costs and the unobservable demands, we assume for empirical purposes that a (3.10a) or (3.10b) equilibrium exists for the J dealers in our markets. See also the following subsection.

$$\begin{aligned}
(1-R_1)\Psi^*(j) &= (c_1 + k_1)\left(1 + \frac{y_1^j}{Y_1 \varepsilon_D^{1+}}\right) \\
(1-R_2)\Psi^*(j) &= (c_2 - k_2)\left(1 + \frac{y_2^j}{Y_2 \varepsilon_D^{2-}}\right) \\
\sum_1^j y_1^j &= -C_D^{1+}(c_1), \quad \sum_1^j y_2^j = -C_D^{2-}(c_2)
\end{aligned} \tag{3.10b}$$

Aggregating again over the participating dealers in both markets we observe that the frictionless equilibrium (3.7) is replaced by the following pair of equations (3.11a)-(3.11b), corresponding, respectively, to the case where the dealer is short (long) in the CDS (LCDS) and long (short) in the LCDS (CDS) market.

$$(1-R_1)\bar{\Psi}^* = (c_1 - k_1)\left(1 + \frac{1}{J \varepsilon_D^{1-}}\right), \quad (1-R_2)\bar{\Psi}^* = (c_2 + k_2)\left(1 + \frac{1}{J \varepsilon_D^{2+}}\right) \tag{3.11a}$$

$$(1-R_1)\bar{\Psi}^* = (c_1 + k_1)\left(1 + \frac{1}{J \varepsilon_D^{1+}}\right), \quad (1-R_2)\bar{\Psi}^* = (c_2 - k_2)\left(1 + \frac{1}{J \varepsilon_D^{2-}}\right) \tag{3.11b}$$

3.5 Entry in the Competitive Cournot Equilibrium under Frictions

In the frictionless market the participating competitive oligopolists are exogenously determined and entry is theoretically feasible at any scale. As pointed out in previous sections, in practice entry is limited by economies of scale at the dealer level under the form of fixed entry costs that prevent small financial institutions from entering.³⁶ Here we show that trading costs as modeled in this section may act as barriers to entry, and a type of (3.11a) or (3.11b) equilibrium may exist where individual dealers may not find it profitable to participate in either one or both markets depending on their utility function. We also show that economies of scale proxied by an increase in the initial endowment W_0^j may overcome the trading cost barriers to small scale entry.

Suppose a type of (3.11a) or (3.11b) Cournot equilibrium exists and consider a “small-scale” entrant $j' \notin j \in [1, J]$ who considers entry at an infinitesimally small output and acts as a price taker. We then prove the following in the appendix.

³⁶ See Atkeson *et al* (2013, p. 11).

Proposition 3: *Given a type (11a) or (11b) equilibrium, a price-taking entry for entrant $j' \notin j \in [1, J]$*

is not feasible in both markets if the following conditions hold

$$c_1 < (c_2 + k_2) \frac{1 - R_1}{1 - R_2} + k_1 \text{ for a type (11a) equilibrium} \quad (3.12a)$$

$$c_1 > (c_2 - k_2) \frac{1 - R_1}{1 - R_2} - k_1 \text{ for a type (11b) equilibrium} \quad (3.12b)$$

Observe that (3.12a-b) define a no trade zone given the relative prices in the two markets that is identical to the zone \mathbb{Z} defined in (4.6) and determined by a no arbitrage model in the following section, with the important difference that the two premiums are values determined by oligopoly, rather than no arbitrage, equilibria. A testable implication of Proposition 3 is that the number of arbitrageurs decreases if the transaction costs k_i , $i = 1, 2$ rise.

The last theoretical result of this paper refers to the role of economies of scale proxied by the initial wealth W_0^j in overcoming barriers to small-scale entry.³⁷ In the appendix we prove the following, under slightly different assumptions.

Proposition 4: *Under the DARA property and assuming constant probabilities $P^S(\tau)$ and $P^D(\tau)$ for all τ an increase in W_0^j may eliminate the barriers to small-scale entry in both the short and the long markets and for both types of equilibria (3.12a) and (3.12b).*

Although Propositions 2-4 do not have empirical implications due to lack of data, they do illustrate the importance of scale in determining the CDS markets' competitive structure. All results hold under general non-competitive conditions and without any restrictions on dealer preferences beyond risk aversion and the DARA property. Still, they are sufficient to test the market power hypothesis, as we show in the following section.

³⁷ A full analysis of entry barriers also needs to consider entry that alters the oligopolistic equilibrium as in Atkeson *et al* (2013). Such an analysis is not feasible without reducing significantly the generality of the modeling of the two-market Cournot equilibrium and lies beyond the objectives of this paper.

4. CDS AND LCDS NO ARBITRAGE PARITY

According to the specifications of CDS and LCDS contracts, which are essentially financial agreements between the protection buyers and protection sellers, the premium of such contracts (denoted by c) received by the protection seller (or paid by the protection buyer) must equalize the value of the expected premium leg to the value of the expected default leg in order to rule out an arbitrage opportunity.³⁸ In a frictionless economy with no search costs this can be expressed mathematically as follows under continuous time,

$$c = \frac{\int_t^T (1-R(\tau))P^D(\tau|t)e^{-\int_t^\tau r(u)du} d\tau}{\int_t^T P^S(\tau|t)e^{-\int_t^\tau r(u)du} d\tau}. \quad (4.1)$$

$R(\tau)$ denotes the time-varying recovery rate; $r(u)$ denotes the time-varying instantaneous interest rate; $P^D(\tau|t)$ denotes the probability that a default event occurs at time τ for the first time conditional on the information at time t ; and $P^S(\tau|t) = 1 - \int_t^\tau P^D(s|t)ds$ denotes the cumulative survival probability of the firm until time τ conditional on the information at time t . Assume a constant interest rate, r , and a constant recovery rate R for all τ ,³⁹ (4.1) becomes

$$c = \frac{(1-R)\int_t^T P^D(\tau|t)e^{-r\tau} d\tau}{\int_t^T P^S(\tau|t)e^{-r\tau} d\tau} \quad (4.2)$$

Define also

³⁸ According to most asset pricing models this value is the present value under a risk neutral distribution derived in equilibrium from the physical distribution of the firm default process.

³⁹ We cannot observe the real recovery rates until default. We assume constant recovery rates for a given pair of CDS-LCDS contracts over time, an assumption used extensively in the literature and consistent with structural models of the firm under both exogenous and endogenous default boundaries. See Leland (1994), Leland and Toft (1996), Collin-Dufresne and Goldstein (2001), Huang and Huang (2012), Huang and Zhou (2008), amongst others. The assumption that the recovery rates estimated at contracting time are equal to the actual recovery rates upon default is shown to be inconsequential in all matured contracts and is also relaxed and discussed extensively in Sections 4 and 7.

$$\int_t^T P^D(\tau|t)e^{-r\tau}d\tau \equiv G(T|t), \quad \int_t^T P^D(s|t)ds \equiv F(T|t) \quad (4.3)$$

Integrating by parts, we find that the denominator of (4.1) with a constant interest rate is given by

$$\int_t^T P^S(\tau|t)e^{-r\tau}d\tau = \frac{e^{-rt}}{r} - \frac{e^{-rT}}{r}[1 - F(T|t)] + \frac{G(T|t)}{r} \quad (4.4)$$

The expressions in (4.2) and (4.3) are given in particular structural models of the firm in terms of the parameters of the asset dynamics process.⁴⁰ The estimation of the parameters could be done by calibrating the particular model to observable variables of the model such as equity prices and bond yields, as shown in our online appendix. Such estimations are, however, not needed for a formal test of the oligopoly model. The US LCDS and traditional CDS issued on the same firm with the same default clause and maturity should share exactly the same first passage default probability and survival probability.

If now we assume homogenous beliefs and free access of investors to both markets then by applying (4.2) to the two markets we observe that the following equality (pricing parity) must be satisfied in no arbitrage equilibrium given no market frictions and no errors in the recovery rate estimates,⁴¹

$$c_1 = c_2 \frac{1 - R_1}{1 - R_2} \quad (4.5)$$

Equality (4.5) is identical to (3.8) for $J \rightarrow \infty$, a proposition that can be tested, by simultaneously taking the appropriate positions in CDS and LCDS where one receives and makes payment in the case of default, with the proper amount based on (4.5). Hence, if the dealer function is competitive and the two markets are integrated the current payoffs⁴² of such portfolios should not deviate from zero extensively beyond covering the dealer costs or other types of frictions.

To account for such costs we generalize the parity relationship (4.5) by incorporating two-way transaction costs as in the oligopoly model of the previous section, which are proportional to the nominal

⁴⁰ See, for instance, Leland and Toft (1996, p. 990).

⁴¹ Also in Ong, Li and Lu (2012).

⁴² “Current payoffs”, “Current deviations” and “Current pricing-parity deviations” are used interchangeably in this paper.

amount of the CDS and LCDS contracts and assumed symmetric for long and short positions without loss of generality.⁴³ In such a case there is a non-trading zone on the CDS leg, denoted by $\mathbb{Z} = [\bar{c}_1, \underline{c}_1]$, where,

$$\bar{c}_1 = (c_2 + k_2) \frac{1 - R_1}{1 - R_2} + k_1, \underline{c}_1 = (c_2 - k_2) \frac{1 - R_1}{1 - R_2} - k_1 \quad (4.6)$$

If the observed CDS spreads fall in the non-trading zone \mathbb{Z} given the corresponding CDS recovery rates, LCDS spreads and recovery rates, there is no trading activity and the current payoffs of the portfolios are equal to zero. Otherwise, we are able to construct a trading strategy to generate non-zero current payoffs. Thus, the set of payoffs (or pricing-parity deviations) are given by,

$$PR_TC = \begin{cases} c_1 - \left[(c_2 + k_2) \frac{1 - R_1}{1 - R_2} + k_1 \right] & \text{if } c_1 > \bar{c}_1 \\ \left[(c_2 - k_2) \frac{1 - R_1}{1 - R_2} - k_1 \right] - c_{CDS} & \text{if } c_1 < \underline{c}_1 \\ 0 & \text{if } \underline{c}_1 \leq c_1 \leq \bar{c}_1 \end{cases} \quad (4.7)$$

Specifically, when the observed CDS spread is such that $c_1 < \underline{c}_1$, we take a long position in one share of the CDS contract with \$1 notional amount where we pay the CDS premium continuously given that no default occurs and we participate in $(1 - R_1)/(1 - R_2)$ shares of the US LCDS short contract with \$1 notional amount per contract where we receive the LCDS premium. Under no arbitrage, given no estimation risk associated with recovery rates and no further market frictions, the current and expected future payoffs for this portfolio are positive and zero, respectively; An equivalent portfolio exists when the observed CDS spread is such that $c_1 > \bar{c}_1$. On the other hand, such portfolios are normal outcomes of market equilibrium under our oligopoly model with entry barriers. Hence, if such portfolios appear frequently and persist over time then either our oligopoly model is validated or other limits to arbitrage in the CDS and LCDS markets are present. In the following sections we use the available empirical data to

⁴³ Given a CDS or LCDS contract with 1\$ notional value and premium c_i , we have to pay $(c_i + k_i)$ when we buy, and receive $(c_i - k_i)$ when we sell.

test the violations of parity between the two markets and attribute them to the relaxation of the appropriate assumptions.

5. THE MAIN EMPIRICAL TESTS: PRICING PARITY VIOLATIONS

In this section we examine the current deviations of the CDS and LCDS parity relation developed in the previous section, which are anomalous under no arbitrage but imply a non-competitive structure in our oligopoly model. We verify whether these deviations lead to frequent positive payoff portfolio strategies and, if yes, what factors may account for these payoffs. The results are presented both without and with transaction costs. In subsequent sections we present further direct tests of the competing no arbitrage and non-competitive structure hypotheses and we also examine whether the positive payoffs are due to our assumptions of certain recovery rates or to the absence of limits to arbitrage.

5.1 Trading Strategies

Following the CDS and LCDS parity in the presence and in the absence of transaction costs discussed in previous sections, we first examine the current payoffs in (4.7) with the observed CDS and LCDS data. Figure 1 reports the distribution of simulated portfolio strategies with transaction costs.⁴⁴

[Insert Figure 1 about here]

In the presence of transaction costs estimated from actual CDS data (see below) we observe that only approximately 19% of the cross-sectional observations in the full sample fall in the no-trading zone \mathbb{Z} and cannot generate positive current payoffs. In both cases, with and without transaction costs, buying CDS contracts and selling the corresponding LCDS contracts dominates the reverse trading strategy.

5.2 Current Payoffs of Liquid Portfolios with Transaction Costs

In this subsection we analyze the current payoffs of our portfolio strategies assuming that the recovery rates reported by the Markit database are the “real recovery rates” once the default events occur.

[Insert Table 2 about here]

⁴⁴ The summary statistics of one-way proportional transaction costs, the time trend of bid-ask spreads and the distribution of simulated trading strategies without transaction costs are reported in Table I, Figure I and Figure II in the online appendix, respectively.

For transaction costs, estimates from the earlier literature are not very helpful, since their time span does not overlap with our sample period.⁴⁵ Since the Markit database only provides the composite quotes for the CDS and LCDS spreads, we match the single names in our sample with the Bloomberg database and find that 61 out of 120 firms are quoted in the Bloomberg historical CDS dataset.⁴⁶ The daily closing bid-ask quote information is retrieved for the time span of our study. Table 2 reports the summary statistics of both firm average and daily average bid-ask spreads.⁴⁷ The median of the daily average bid-ask spreads at around 18 basis points is a little lower than but close to the numbers documented by Acharya and Johnson (2007) and Tang and Yan (2008). The positive skewness and extremely high kurtosis imply fat tails, especially on the right. The mean of around 35 basis points is relatively high compared to the median, driven by outliers during the crisis.⁴⁸

Intuitively, the transaction costs in the LCDS market should be greater in relative terms than their counterparts in the CDS market since the LCDS market is relatively smaller and less liquid. On the other hand, the lower credit spreads for the LCDS contracts would normally imply (at equal liquidity) lower absolute bid-ask spreads for LCDS. Since there is no data for the real bid-ask spreads in the LCDS market, we use the CDS absolute spreads for the LCDS market as well. Table 3 presents the numerical results of our portfolio strategies based on (4.7) in the presence of time-varying bid-ask spreads, assumed the same for every firm in our sample and equal to the daily average of the Bloomberg sample.⁴⁹

[Insert Table 3 about here]

⁴⁵ See Table 1 in Acharya and Johnson (2007, p. 117), as well as the summary statistics results in Table 1 and Table 3 in Tang and Yang (2008), who report estimates around 20 or 22 basis points.

⁴⁶ As Bloomberg does not provide the information about restructuring clauses, we can only match with firm name and we need to assume that the restructure clauses are the same as for the single name contracts in the Markit database.

⁴⁷ Summary statistics for proportional transaction costs are reported in Table II of our online appendix.

⁴⁸ In Figure I of our online appendix we show the time trend of the daily average bid-ask spreads across the firms of our sample for which Bloomberg data is available; the highest values are from October 2008 to July 2009.

⁴⁹The results summarized in Panel A of Table III of our online appendix are very similar if the daily average proportional bid-ask spread is used to calculate the transaction costs in (4.7). Note that, in view of the highly skewed distribution of the bid-ask spreads, the use of the average overestimates the impact of the transaction costs in (2.7) and understates the payoffs of our portfolio strategies. In addition, we show that the current payoffs of the simulated portfolios with real bid-ask spreads for our Bloomberg and Markit intraday sub-samples are also very positive (see Table IV in our online appendix).

Table 3 reports the payoffs of our simulated portfolios with transaction costs. The mean and median returns increase as the rating status deteriorates, with the not-rated contracts generating the highest current payoffs among all the sub-samples. As the time span of the single name contracts varies, the cross-sectional average puts more weight on the firms with longer lives. To remove this bias, we first calculate the daily average current payoffs for each single name across the life of the contract and then present the statistical properties of the sample reported as “Firm Daily Average Current Payoffs”. The distribution has a 4.5% mean and 2.5% median return, which are even greater than those based on the cross-sectional observations.

[Insert Figure 2 about here]

To check the time trend of the current payoffs, we aggregate the value of current payoffs per day across all the available paired single name contracts on that day and then divide by the total number of single name contracts per day to construct a payoff index. As expected, the distribution of index returns is almost Gaussian for all the samples. As in the cross-sectional results, the average current payoff increases as the rating deteriorates, and the not-rated sub-sample dominates in terms of the mean and median of all the rated sub-samples but also has the highest standard deviation, 3.16%. The time trend of daily average current payoffs of the different samples can be observed in Figure 2, both with and without transaction costs, with the two cases being very close to each other. In the full and investment grade samples we note that the current payoffs are relatively higher during the recession period from mid-2008 to late 2009 compared to the other time periods, and gradually decrease in recent years. The junk-rated and not-rated samples have significantly higher volatilities than the investment grade firms. Both junk-rated and not-rated firms sub-samples are small firms in terms of total assets and have relatively lower tangible ratios which make them more vulnerable, especially in turbulent financial market environments. These style factors contribute to the higher volatilities for these two sub-samples compared to the investment grade firms.

5.3 A Naïve Trading Strategy

While the estimated CDS and LCDS recovery rates are inputs to justify the choice of trading strategy, it is impossible to observe the real recovery rates until a firm defaults. In this robustness test, we rule out this uncertainty from the trading strategy selection process and pursue a naïve trading strategy under which we always pay the CDS premium and receive the corresponding LCDS premium. Interestingly, we are still able to document daily abnormal current deviations in terms of their mean and median of approximately 1.52% and 0.64%, respectively, for the full sample.

Summarizing our numerical results, we note that the observed CDS and LCDS prices do not satisfy the no arbitrage parity relation (4.5), even with the inclusion of generous transaction costs as in (4.6)-(4.7). They show that in most cases (but not always) that the LCDS contracts are over-valued, and that taking advantage of the recovery rate estimates improves the profitability of trading strategies.

5.4 Possible Explanations

If a zero net cost portfolio generates positive payoffs in a no arbitrage model then there are three possible reasons. The most commonly invoked justification is that the payoffs are rewards for risk. Unlike other similar arbitrage-like strategies involving different financial instruments in which model error is always present, such risk is relatively easy to evaluate in our case. It appears only in the case where the underlying firm defaults prior to contract maturity, and arises either from incorrect estimates of the recovery rates in (4.7) or from counterparty default. Alternative explanations in a no arbitrage context are the often invoked limits to arbitrage such as margins, liquidity, or slow moving capital.⁵⁰ With the exception of the latter factor, the others are also characteristics of a non-competitive market structure and have been incorporated into our oligopoly model of Section 3. We deal with each in turn.

5.5 Reward for Risk? Evidence from Matured Contracts

For the payoffs to be rewards for risk the portfolio strategies must occasionally produce losses at contract maturity. Although it is not possible to observe ex post the payoffs of our portfolios for the 5-year CDS-LCDS contract pairs, such verification is feasible for subsets of our 1- and 3-year samples.

⁵⁰ Shleifer and Vishny (1997), Mitchell, Pulvino and Stafford (2002), and Duffie (2010).

Since the screening rule for profitable portfolios on the basis of the available data is identical for these short term contracts and our 5-year sample, the reliability of the recovery rate estimates can be assessed from the matured contracts. For the one-year subsample ending on March 19, 2011 there are 31,493 observations consisting of 70 firms between April 11, 2008 and March 19, 2011, of which 11,425 observations are after April 5, 2010, when the LCDS contracts became fully non-cancellable. Using Moody's default and recovery data base, we find four default events on three firms because of distressed exchange.⁵¹ In all cases the observed recovery rates maintain or enhance the payoffs of the portfolios selected by the estimated recovery rates in the Markit data base. Assuming the average trading size of a CDS contract of \$5 million according to the empirical data, we calculate the dollar trading profit after incorporating the transaction costs for each contract.⁵² For simplicity, we ignore the time value of money and find that the 1-year sample could generate around \$3.272 billion in profits using our CDS-LCDS parity trading strategy.

A similar picture emerges when we examine the 3-year contracts ending on March 19, 2009, for which our sample covers the entire life of the contracts. This 3-year subsample consists of 7397 contracts on 61 firms. After verifying the few recorded defaults according to Moody's default and recovery database we apply the same payoff estimation and find that all contracts were profitable. Using again the same average CDS contract size and ignoring the rate of interest, we document approximately \$3.652 billion in abnormal profits.

In other words, out of a sample of more than 18,000 observations capable of generating more than \$6.9 billion of profits from our zero net cost portfolio strategies there was not a single instance of recorded losses. With such results the reward for risk explanation is not credible and must be discarded: positive payoffs may not be arbitrage profits theoretically, but they are certainly such profits in a statistical sense. Nonetheless, we re-examine in our robustness checks and our online appendix both

⁵¹ CCU on Aug, 27th, 2009 with real recovery rates 32%, LVLT on Dec 23rd, 2008 and Jun 26th, 2009 with real recovery rates 96% and 100% and UIS on July 31st, 2009 with real recovery rates 99%.

⁵² We consider each observation as an independent contract on each day. A default event of a firm triggers the payments of all the on-going CDS contracts. The loss given default is paid based on the real recovery rates reported in Moody's dataset. Meanwhile, all the CDS premiums stop on such firms upon the arrival of default.

recovery rate uncertainty and counterparty risk for our five-year contracts, which is discussed in detail in Section 7.

5.6 Limits to Arbitrage or Non-Competitive Market Structure?

The alternative explanations of limits to arbitrage or non-competitive market structure are qualitatively very different justifications for the observed positive payoffs. The former accepts the validity of (4.5) in the frictionless markets and expands the definition of trading frictions beyond (4.6)-(4.7) to demonstrate the inability of inter-market trading to take advantage of its violations. The latter demonstrates that (4.5) does not hold if either one of the two markets is non-competitive, and attributes the payoffs to the inability of competition to eliminate the profits. In fact, however, the two alternative explanations blur at the edges, as we showed in our oligopoly model of Section 3. For instance, illiquid markets, a cornerstone of the limits to arbitrage approach, imply that entering into a market in a timely manner would impact the price, as in the net demand functions of Section 3, unlike the infinitely elastic demand curves of perfect competition. Nonetheless, under limits to arbitrage the positive payoffs are anomalous and the markets should converge to the no trading zone, unlike oligopoly. We examine these issues in the next section.

6. EMPIRICAL TESTS OF MARKET STRUCTURE AND LIMITS TO ARBITRAGE

6.1 Control Variables Affecting the Integration of the Two Markets

Before testing the competing hypotheses we need to control for both firm-specific and macro variables that affect market conditions. These are chosen from the existing credit spreads literature,⁵³ after reflecting multicollinearity⁵⁴ and data availability. These variables are particularly important in the oligopoly model, since they affect the parity relation through the demand curves in both markets, in addition to the recovery rates. The latter are the only ones affected under the no arbitrage hypothesis.⁵⁵

⁵³ See Collin-Dufresne, Goldstein and Spencer (2001), Acharya, Bharath and Srinivasan (2007), Acharya and Johnson (2007), Ericsson, Jacobs and Oviedo (2009) and Cao, Yu and Zhong (2010).

⁵⁴ For instance, we use the yields on 5-year US treasury bonds since both CDS and LCDS contracts in our sample have five years to maturity. We use the spread between the yields on Aaa and Baa corporate bonds (CBS) and eliminate the VIX because we find that these two variables are highly correlated and that the CBS has better explanatory power than VIX. The correlations between the variables are reported in Table XI in the online appendix.

⁵⁵ We also expect under both hypotheses a widening of the no trading zone during the crisis because of the increase in transaction costs.

a. Firm-specific variables

We use the logarithm of total asset (*LOGA*),⁵⁶ current ratio (*CAL*),⁵⁷ leverage ratio (*LEV*),⁵⁸ tangible assets (*TANG*)⁵⁹ and idiosyncratic volatilities (*IDIO*) to control for the firm-specific characteristics. To obtain *IDIO*, we first calculate the daily returns using $r_{it} = p_{it}/p_{it-1} - 1$, where p_{it} denotes the daily closing equity price for firm i at day t , and then run the following regression using the Fama-French three-factor model to get the residual ε_{it} ,

$$r_{it} - rf_t = \alpha_t + \beta_1 (R_t - rf_t) + \beta_2 SMB + \beta_3 HML + \varepsilon_{it} \quad (6.1)$$

The idiosyncratic volatilities, $\sqrt{h_{it}}$, which are the conditional volatilities of the residuals, are filtered by an EGARCH model, given as follows,

$$\begin{aligned} \varepsilon_{it} &= \xi_{it} \sqrt{h_{it}}, \xi_{it} \sim N(0, \sqrt{h_{it}}) \\ \ln(h_{it}) &= \omega + \beta \left[\theta \xi_{it-1} + \gamma (|\xi_{it-1}| - E|\xi_{it-1}|) \right] + \alpha \ln(h_{it-1}) \end{aligned} \quad (6.2)$$

Idiosyncratic volatility is used in the literature as a firm-specific measure of pricing uncertainty or price informativeness or informational asymmetry.⁶⁰ We conjecture that higher idiosyncratic volatilities are associated with lower market efficiency. In the oligopoly model these volatilities are also expected to reduce the demand elasticity in both markets, although the net effect on the key relation (3.8) cannot be predicted. We also conjecture that higher idiosyncratic volatilities would be associated with increased current payoffs.

b. Macro variables

Publication of ISDA dummy (ISDA): The International Swaps and Derivative Association (ISDA) released after the sub-prime financial crisis a series of publications providing guidance and standards to try to protect investors and improve the efficiency of the CDS market. We examine the impact of the

⁵⁶ The sum of book value of total liabilities and the market value of total equity (traded and non-traded).

⁵⁷ Current assets divided by current liabilities.

⁵⁸ Total liabilities divided by total assets.

⁵⁹ The total value of property, plant and equipment divided by total assets.

⁶⁰ For the informativeness of idiosyncratic volatility see Brockman and Yan (2009), Chen, Huang and Jha (2012), Krishnaswami and Subramaniam (1999), and Lee and Liu (2011).

release on April 5, 2010 of a series of documents published by the ISDA regarding the North American Loan CDS market and described in the appendix. The *ISDA* dummy variable is equal to zero before and including the April 5 2010 ISDA publication day and equals one after this date. Since the LCDS market should become more efficient and deviations from efficiency should decrease with standardization, we expect a negative coefficient for this dummy variable.

Macro variables associated with the business cycle: There are four such variables, the 5-year US treasury bond yield (*TB5Y*), the slope of the term structure (*SL*) measured by the difference between the yields on 5- and 1-year US treasury bonds, the yield spread between Aaa and Baa corporate bonds (*CBS*), and the return of the S&P 500 total return index (*SP*).

These four variables are leading indicators of the business cycle. With the exception of *CBS*, whose increase is associated with weakening prospects for the economy, increases in the other three factors indicate a stronger economy. The effects of these variables on the current payoffs of our portfolio strategies are by their nature ambiguous, since they affect all four variables on both sides of the parity relation (4.5). They affect the spreads directly because of their obvious impact on the default probabilities, but also affect both recovery rates indirectly, since the latter tend to increase when economic prospects improve. For *CBS* the CDS/LCDS spread ratio effect, which increases almost by definition when *CBS* increases, is likely to dominate the indirect recovery rates ratio, thus increasing the divergence and predicting higher current payoffs when *CBS* increases and a positive coefficient for this variable.

However, no clear a priori prediction about the direction of the impacts of the other three variables can be formulated. Even if we assume that both spreads and recovery rates for LCDS are relatively unaffected by the state of the economy, the latter would impact in opposite directions CDS spreads and recovery rates and affect both sides of the parity relation (4.5) in the same direction, with the net effect impossible to predict. All one can conjecture is that these divergent effects will weaken the explanatory power of these variables with respect to the current payoffs in the panel regressions.

The accounting variables, including total assets, book value of total liabilities, market value of equity, current assets, current liabilities and tangible assets, are obtained from the COMPUSTAT database via the

WRDS platform. The data are updated quarterly. For our initial regressions, we convert the frequency from quarterly to daily by keeping the value constant within each quarter and then take a one quarter lag. The fixed income macro variables, including the yields on 1- and 5-year US treasury bonds, and Aaa and Baa corporate bond yields are obtained from the US Federal Reserve H15 database. The equity prices and S&P 500 total return index data are obtained from Bloomberg.

6.2 Market Structure Hypotheses

Equation (3.7) is the key empirical relation. The right-hand-side (RHS) is observable as an estimate (assumed unbiased), while in the left-hand-side the observable ratio of the spreads is multiplied by the

unobservable ratio of the modified elasticities, $\frac{(1 + \frac{1}{J\varepsilon_D^1})}{(1 + \frac{1}{J\varepsilon_D^2})} = \frac{\varepsilon_D^2(1 + J\varepsilon_D^1)}{\varepsilon_D^1(1 + J\varepsilon_D^2)}$. Note that J is the number of

arbitrageurs common to both markets. An imperfect proxy, an upper bound of this number, is the *minimum* of the number of quotes in the CDS or LCDS markets in a given day. As for the other traders beyond the minimum, they obviously are participants in only one market and can be included in the definition of net demand.

The derivative with respect to J of the ratio $\frac{1 + J\varepsilon_D^1}{1 + J\varepsilon_D^2}$ has the sign of the difference $\varepsilon_D^2 - \varepsilon_D^1$, which

we cannot infer a priori for the two markets. However, we can surmise that this difference, as well as the ratio of the elasticities, will increase as the difference in the number of traders in the two markets increases. Also, the profits from arbitrage should increase as J decreases. We construct the following two hypotheses to test the empirical implications from the market power hypothesis:

H1: *The profits from the parity violations will increase as the minimum number of quotes in the two markets decreases.*

H2: *The parity violations profits will widen as the difference in the number of quotes rises.*

[Insert Table 4 about here]

In the tests in this section we use the number of distinct dealers providing quotes for 5-year CDS and LCDS contracts as a proxy for the number of dealers in these markets. Before testing the validity of the proposed hypotheses, we conduct an initial examination to detect the market structure according to equation (3.8) by running the following regression:

$$\begin{pmatrix} c_1 \\ c_2 \end{pmatrix}_{it} = \hat{\Phi} \begin{pmatrix} 1-R_1 \\ 1-R_2 \end{pmatrix}_{it} + \beta \left(Crisis\ Dummy * \frac{1-R_1}{1-R_2} \right)_{it} + \alpha Diff_Dealers + \varepsilon_{it} \quad (6.3)$$

Where *Crisis Dummy* equals one if the date is before April 1st, 2009 and zero otherwise; *Differ_Dealers* denotes the difference in the number of distinct dealers providing quotes in the CDS and LCDS markets at each time t. As reported in Table 4, the coefficients of the recovery rate ratios are all significantly different than one, suggesting an oligopoly structure, which is consistent with our conjectures. Since $\hat{\Phi} = (1 + \frac{1}{J\varepsilon_D^2}) / (1 + \frac{1}{J\varepsilon_D^1})$ according to equation (3.8), a coefficient significantly less than one also suggests that $\varepsilon_D^1 < \varepsilon_D^2$. In addition, we note that the recent sub-prime financial crisis starting from the end of 2007 significantly affects the market structure of the credit default markets and increases the elasticity of the CDS market compared to the LCDS market.

[Insert Table 5 about here]

Hypotheses H1 and H2 are tested directed by regressing the parity violations profits against our proxy for the difference in dealer participation in the two markets and the control variables discussed above. We report the regression results in Table 5. First, we document a significant negative coefficient for the differences in the number of quotes of around -0.12% at the conventional level, supporting the conjecture of H2. The coefficients for the minimum number of quotes for the main sample and all the subsamples are negative but not significant at the conventional level. Applying the timeline of global financial crisis defined by the change of the spread between London Inter-Bank Offered Rates (Libor-OIS) and Overnight Index Swaps (OIS) in Ait-Sahalia et al. (2012), we separate our sample into in-crisis

and after-crisis groups using the crisis cut-off date of March 31, 2009. We note that the negative relationship between the profits and the difference in the number of quotes increases and becomes significant after the financial crisis. In addition, the firm credit rating does not affect such negative relationships materially.

An alternative classification of the explanatory factors for the parity violation profits is in terms of the strategies that dealers use to exploit them, short CDS or short LCDS as in (3.10a) and (3.10b) respectively. Table XIX in our online appendix presents the regression results for this classification for the overall and the in-crisis samples. The short LCDS results for the entire sample are virtually indistinguishable from the full sample results of Table 4, which is not surprising since they form the bulk of that sample's observations. Of interest is also the fact that the short CDS results respond very strongly to the deteriorating prospects of the economy, as shown by the large coefficient of the variable *CBS*: the deteriorating status of all firms prompts higher increases in demand of the agents trading only in the CDS market, yielding higher relative prices than parity dictates in that market. Of more interest is this same short CDS regression for the in-crisis sample, in which the premium effects of the high CDS demand are tempered somewhat by the competition variable of the difference of quote-providing dealers, whose coefficient is negative and strongly significant.⁶¹

6.3 Analysis of Slow-moving Capital

Compared to the traditional financial markets, the credit derivative markets are less competitive, particularly the LCDS market as reflected in the number of distinct dealers providing quotes. Consequently, the existence of potential arbitrage profits might just reflect the slow movement of capital into these markets. Nonetheless, under limits to arbitrage in the form of slow-moving capital there should be lower duration in the arbitrage profit (rather than the no profit) states, and this duration should decrease with the size of the arbitrage profits. The following three hypotheses are direct tests of limits to arbitrage:

⁶¹ Note that in almost all cases the change in competition takes place only in the CDS market, since there are very few dealers providing quotes for LCDS. The tightening of the parity relation violations affects the payoffs no matter which markets the dealers are short in.

H3: The persistence of observed arbitrage profits states is lower than that of absence of profits states.

H4: The duration of arbitrage profits states decreases with the size of observed profits.

H5: In arbitrage profits states the CDS and LCDS premiums should change in the direction of the elimination of profits.

[Insert Table 6 about here]

To test H3 we count the number of consecutive days on which a particular CDS-LCDS pair persists in an arbitrage profit or no-profit state once we observe an arbitrage profit opportunity (or lack thereof) according to the CDS-LCDS parity rule presented in the previous sections. Based on the results reported in Table 6, we find that the median number of days of persistence or duration of arbitrage profits is 5 (3) days when the CDS contracts are much cheaper (more expensive) compared to their corresponding LCDS contracts. Interestingly, the shortest period is for the no-profit state, and especially for the no-rating subsample. The extremely high mean of about 52 days for the majority case is driven by some extreme cases and strong positive skewness since this variable is truncated at zero. The no-rating subsample and the post-crisis period show the highest persistence in one of the profit states and the lowest persistence in the no-profit state. In other words, the market seems to respond fastest to the *absence*, rather than the presence of parity violations, directly contradicting H3. Also, the parity violations are not related to the crisis.

[Insert Table 7 about here]

To test H4 we estimate a panel regression with single-name fixed effects that adds arbitrage profits on the day first observed (*Profit_TC*) as an independent variable. The dependent variable measures the duration of the persistence of arbitrage profits by the number of consecutive days for which the arbitrage profits continue to be positive after first observed. This persistence measure is winsorized at the 5% and 95% levels to mitigate the impact of extreme values. Our expectation is that the coefficient estimates for *Profit_TC* should be negative if H4 holds, since capital should move faster in response to higher arbitrage

profit opportunities. Based on the results reported in Table 7, we observe positive estimated coefficients for *Profit_TC* that are significant at the 0.05 level or better for all but the speculative subsample (significant at 0.10 level). Thus H4 is decisively rejected, in contradiction to the slow-moving capital or, indeed, to any other limits to arbitrage factors. The duration of arbitrage profits increases with an increase in the magnitude of arbitrage profits as predicted by the oligopoly market model. This result is the single most powerful rejection of limits to arbitrage and support for the financial oligopoly hypothesis.

Last, for H5 we construct a diverging ratio to measure the persistence of all the possible arbitrage opportunities based on parity violations. This measure is inspired by the *K*-metric developed in Kapadia and Pu (2012). Assume that we have $l = 1, \dots, N$ pairs of CDS and LCDS contracts on a given date and the total number of periods in our sample is denoted by τ , where $1 \leq \tau \leq N - k$ and $k \leq M - \tau$. According to equation (4.7) with proportional transaction costs, we define,

$$\begin{aligned}\widehat{c}_{CDS}^U &= (c_{LCDS} + k_{LCDS}) \frac{1 - R_{CDS}}{1 - R_{LCDS}} + k_{CDS} \\ \widehat{c}_{CDS}^L &= (c_{LCDS} - k_{LCDS}) \frac{1 - R_{CDS}}{1 - R_{LCDS}} - k_{CDS}\end{aligned}\tag{6.4}$$

If we observe $c_{CDS} < \widehat{c}_{CDS}^L$ on day 0, we define the diverging changes as,

$$\begin{cases} \Delta c_{CDS} < 0, \Delta \widehat{c}_{CDS}^L > 0 \\ \Delta c_{CDS} > 0, \Delta \widehat{c}_{CDS}^L > 0 \text{ and } \Delta c_{CDS} < \Delta \widehat{c}_{CDS}^L \\ \Delta c_{CDS} < 0, \Delta \widehat{c}_{CDS}^L < 0 \text{ and } \Delta c_{CDS} > \Delta \widehat{c}_{CDS}^L \end{cases}\tag{6.5}$$

Where Δc_{CDS} and Δc_{LCDS} denote the change of CDS and LCDS spreads. If we observe $c_{CDS} > \widehat{c}_{CDS}^U$ instead, we define the diverging changes as,

$$\begin{cases} \Delta c_{CDS} > 0, \Delta \widehat{c}_{CDS}^U < 0 \\ \Delta c_{CDS} > 0, \Delta \widehat{c}_{CDS}^U > 0 \text{ and } \Delta c_{CDS} > \Delta \widehat{c}_{CDS}^U \\ \Delta c_{CDS} < 0, \Delta \widehat{c}_{CDS}^U < 0 \text{ and } \Delta c_{CDS} < \Delta \widehat{c}_{CDS}^U \end{cases}\tag{6.6}$$

We define the diverging ratios as,

$$DR = \frac{\sum_{\tau=1}^{N-1} \sum_{k=1}^{N-\tau} 1_{[Diverging\ Change]}}{N(N-1)} \quad (6.7)$$

This nonparametric measure is independent of the time period since it accounts for all the pairings of CDS and LCDS and all the possible combinations from the N observations. Furthermore, this measure is based on standard statistical properties and is not impacted by nonlinearities.

[Insert Table 8 about here]

Descriptive statistics are reported in Table 8 for the diverging ratios (DR) calculated using the overlapping windows with varying window sizes for each firm. The diverging ratios for the full sample only vary slightly from 5 to 60 days, implying persistence in the arbitrage opportunities in the CDS and LCDS markets. This finding is robust for sub-samples based on credit ratings or position in the economic cycle. These results show conclusively that there is no pattern in the movements of the relative spreads in connection to the observed parity violations, directly contradicting H5. The median DR is around 50% for the full sample in all cases, both in- and post-crisis.

6.4 Conclusions of the Empirical Tests

As noted in Section 4, of the three competing explanations for the pricing parity violations only limits to arbitrage and market structure remain after the elimination of the observed profits as rewards for risk. Although limits to arbitrage is the most popular explanation among finance researchers for such violations, the evidence for the existence of an oligopolistic structure in all CDS markets at the dealer level provided in Section 2 is conclusive and cannot be ignored. The effect of such an oligopoly is demonstrated in Section 3, in which the pricing parity violations and trading profits are present even in the absence of collusion. The empirical evidence in this section overwhelmingly supports this oligopoly model, since limits to arbitrage are inconsistent with the observed absence or perverse market response to the observed pricing parity violations and to the sensitivity of the violations to the competitive status of the CDS markets.

7. ROBUSTNESS CHECKS

In this section and in our online appendix we revisit the justification of the observed parity violations and positive portfolio payoffs as rewards for risk. As we saw, such a justification is not warranted for the one- and three-year contracts, but it may have some credibility for the more liquid five-year contracts that form the bulk of our data and empirical work. Accepting the reward for risk explanation for the observed payoffs essentially implies that the screening rule (4.6)-(4.7) for mispriced contracts is unreliable. Since, unlike other similar arbitrages in the financial literature,⁶² the recovery rates in the Markit data base are the only estimates of unobservable factors in the relations, their reliability needs to be verified. This is done in the next subsection, while subsections 7.2 and 7.3 deal with liquidity and counterparty risk in the limits to arbitrage scenario.

7.1 Uncertainty of Recovery Rates: Quality and Bias of the Markit Estimates

a. Impact of Absolute Priority Rule

The priority of the LCDS over the CDS claims in the event of default is a key issue in assessing the *future* payoffs of our portfolios in case a default event occurs. As a rule, syndicated secured loans have claim priority compared to the senior unsecured debts implying a 100% recovery for LCDS-underlying loans before the recovery for CDS debts can become positive. To understand the role of such priority, we denote by R_{CDS}^r and R_{LCDS}^r the realized (as distinct from the Markit estimates) recovery rates at default and consider the future payoffs of portfolios such that $c_{CDS} < \underline{c}_{CDS}$ in (4.7). The payoff to that portfolio in the event of default is

$$1 - R_{CDS}^r - \frac{1 - R_{CDS}}{1 - R_{LCDS}} (1 - R_{LCDS}^r) = 1 - R_{CDS}^r - (1 - R_{CDS}) \frac{1 - R_{LCDS}^r}{1 - R_{LCDS}} \quad (7.1)$$

If there is no error in the estimate R_{LCDS} then the payoff is equal to $R_{CDS} - R_{CDS}^r$. Similarly, the payoff is always nonnegative whenever $R_{LCDS}^r = 100\%$ and strictly positive if $R_{CDS}^r = 0$ and $R_{LCDS}^r \geq R_{LCDS}$. In other words, these portfolios, in addition to the current positive payoffs, have *always*

⁶² See, for instance, the model-based arbitrage strategies in Duarte, Longstaff and Yu (2007).

nonnegative future payoffs under LCDS priority and full recovery. To evaluate the impact of LCDS priority in the event of default we relax the assumption that R_{LCDS} is an accurate estimate of the real recovery rates for the LCDS-underlying assets. The data and details of the tests are reported in Table IX of our online appendix.

Overall, the data in that table strongly suggests that our potential payoffs from pricing parity deviations which are based on the Markit data base estimates of both CDS and LCDS recovery rates are, if anything, highly conservative. Recall that when concurrent default occurs, we receive in the overwhelming majority of pricing parity violations cases the loss given default on the CDS leg and pay the loss given default on the LCDS leg, as in relation (4.7).

Hence, the available empirical evidence about the real recovery rates implies that in the overwhelming majority of cases the current payoffs on the simulated portfolio will be augmented by future payoffs when default occurs, thus increasing the profitability of our portfolio strategy. Such a conclusion implies, in turn, that in the absence of liquidity considerations the observed structure of the premiums in the CDS and LCDS markets indicate that trading in the two markets takes place without taking into account the LCDS priority rule in the event of default. Such segmentation is present in the oligopoly model of Section 3, due to the barriers to entry at the dealer level.⁶³

On the other hand, the future payoffs upon default will be negative for the portfolios that pay the LCDS and receive the CDS premium. Apart from the fact that these cases are relatively few, they do not necessarily negate the observed abnormal current payoffs. The reason is that all one has to do is refrain from trading in these cases if the evidence from Table 3 is confirmed with more extensive data on actual defaults and recoveries. These cases are analyzed further in our online appendix, where it is shown that they offer further supportive evidence of market segmentation.

b. Structural Model Implied Recovery Rates

⁶³ Similar anomalous relations have been observed in the index and equity option markets by Driessen, Maenhout and Vilkov (2009) and the index futures options and underlying market by Constantinides *et al* (2011).

We also verify whether our results hold when we estimate the recovery rate by a structural no arbitrage model that treats corporate debt and equity as contingent claims on the firm's assets and links default risk and firm characteristics. We combine the information from different financial markets, including equity and option markets, with accounting information to calculate the model implied recovery rates and search for pricing-parity violations with these new recovery rates. We also obtain estimates of the expected future payoffs upon default, analyzed in the next subsection.

Our structural model is the one presented in Leland and Toft (1996). Although this model's capital structure differs from the structure of the firms in our sample, it is the most popular bond pricing structural model in the literature and has two important advantages. First, Leland and Toft (1996) use the endogenous default boundary that is chosen by the firm itself, and second it presents closed form expressions for all the variables of interest, which provide significant computational convenience for the estimation. The details of the model, the data description and the Generalized Method of Moments (GMM) procedures are reported in our online appendix.

[Insert Table 9 about Here]

Table 9 reports the results of the GMM estimations and the new current payoffs using the implied CDS recovery rates from the structural model. In Panel A, the implied CDS recovery rates on average are very close to the estimates provided by the Markit datasets, especially the results (around 35%) using put option implied equity volatilities. The high standard deviation of 25.34% and 24.22% for results with option implied volatilities and realized volatilities respectively, across all the firms indicates that the cross-sectional effect is very important. The asset volatilities are approximately 10% under both option implied and realized volatilities and are very persistent across all the firms as indicated by the low standard deviations.

Using the model implied CDS recovery rates as being constant across the whole time period for each firm,⁶⁴ we repeat the computations of the current payoffs and report the results in Panels B and C for option implied and realized equity volatilities, respectively. Compared to the current payoffs under the estimated recovery rates (see Panel B of Table 2), the means of the current payoffs under the structural model implied CDS recovery rates are much lower at 2.74% and 2.83% for option implied and realized equity volatilities, respectively, but the corresponding medians are much higher at 1.35% and 1.44%, respectively, for the cross-sectional daily observations. In addition, the results are very similar for both the firm average and daily average samples. These positive and large abnormal current payoffs on the portfolios, evaluated under two very different methods that use partly different data sets, confirm the failure of simultaneous trading in both markets to equalize the spreads in the CDS and LCDS markets.

7.2 Contract Liquidity and the Term Structure of the Portfolio Current Payoffs

The previous analyses focus mostly on the 5-year CDS and LCDS contracts which are the most liquid contracts in these markets. In this section, we expand our sample to other maturities, including 1-year, 3-year, 7-year and 10-year maturities. Due to the illiquidity and data availability of contracts for the other maturities, the total number of cross-sectional observations is reduced from 69,805 to 33,377 after deleting the observations with missing variables. If illiquidity of the contracts is the factor responsible for the large current payoffs of the pricing parity violations portfolios then we should observe more of them for these more illiquid contracts than for the 5-year ones.

[Insert Figure 3 and Figure 4 about here]

Figure 3 exhibits both the medians and means of the current payoffs on the portfolios consisting of CDS and LCDS contract pairings across the different maturities in the presence of transaction costs.⁶⁵ The distributions of these current payoffs across all the maturities are highly positively skewed since all the means (around 2.8% in average size) are significantly greater than their corresponding medians

⁶⁴ We use estimated LCDS recovery rates provided by Markit. As the underlying asset of LCDS is syndicated secured loans which usually have collateral backing and are senior to the senior unsecured debts, the recovery rates are much easier to estimate.

⁶⁵ The transaction cost information represented by the bid-ask spreads is collected from Bloomberg for the different maturities.

(around 1% on average). There is a clear upward trend for the median current payoffs as the maturity increases from 1 to 5 years before it becomes flat for the longer maturities. Nevertheless, the mean payoffs exhibit a flat term structure. As the value of current payoffs on the portfolios with zero-expected payoffs measure the deviations from the CDS and LCDS parity described in Section 1, we expect to observe fewer violations of the parity relation for short-term contracts because of the reduced probability of the default event during contract life.

Figure 4 shows the distribution of the trading strategies across all the maturities we considered. We document that for the shortest (1-year) maturity approximately 35% of the observations, the highest percentage among all the maturities, do not violate the CDS and LCDS parity, as expected; recall that for these contracts all of our simulated portfolios in cases of violations turned out to be profitable. The violation percentage increases as the maturity increases from 1 to 5 years and stays approximately constant thereafter. Since the contracts with 5-year maturity are the most liquid ones in our sample, these results suggest that contract illiquidity is not a factor in the incidence of parity violations. These results actually constitute further evidence against limits of arbitrage and in favor of the oligopoly model in which illiquidity is built into the model and explains the profitable strategies.

Across all the maturities, paying the CDS premium and receiving the corresponding LCDS premium dominates the other trading strategies. This confirms our earlier findings that the observed CDS premiums are too cheap given the corresponding LCDS premiums, and expected CDS and LCDS recovery rates. We also note that the percentage of receiving CDS premiums and paying corresponding LCD premiums slightly increases as the maturity increases from 1 to 7 years.

7.3 Counterparty Risk

Counterparty risk in a CDS market (i.e., the risk associated with a counterparty failing to honor its obligations) was at the center of the 2008 financial crisis, which was caused in part by the near failure and bailout of the American International Group (AIG), a leading seller of CDS contracts. As discussed in Section 2, the evolving regulatory environment and the introduction of CCP's and margins was in part

intended to eliminate it.⁶⁶ Since it evolved during our data period and our data base does not distinguish between trades that went through a CCP and the others, we cannot evaluate its role in explaining the positive payoffs in a no arbitrage scenario. Nonetheless, since Arora, Gandhi and Longstaff (2012) find that the magnitude of the counterparty risk that is priced is vanishingly small,⁶⁷ the counterparty risk premium might be able to explain only a very small portion of the abnormal current deviations when the intermediate investor has lower credit risk than the CDS (LCDS) protection seller. Otherwise, the counterparty risk should have no impact on CDS and LCDS parity due to the nature of the risk transfer.

7.4 Margins

When considering the role of margins as a barrier to entry, we first note that traders are allowed to net out their margin positions, with the result that the collateral to gross notional ratio in CDS trades was 0.78% in 2001, which was far below the ICE margins, as noted in Duffie *et al* (2015). In the absence of such data for the LCDS market and the identities of the traders in both markets it is not possible to assess the net margin necessary for our pricing parity violations portfolios. Nonetheless, we conduct robustness checks by examining the role of margins for the matured one-year contracts using the ICE margins under the most adverse conditions.

[Insert Table 10 about here]

We consider scenarios with margin requirements from 0% up to 10% and a cost of capital from 5% to 10%. As indicated by a regulatory note from FINRA, the margin requirements for the short position are much higher than the long position in credit default swap markets. To capture this differential requirement, we include scenarios where the margin requirements for short positions are double those for long positions. Given a 0.78% margin requirement, the aggregate dollar profits are \$3.13 and \$2.87 billion when the cost of capital is 5% and 10%, respectively, under the worst scenarios. Considering the

⁶⁶ The impact of the central clearing counterparty (CCP) on the CDS market's counterparty risk is unclear. For instance, Duffie and Zhu (2011) show an increase of counterpart risk in the presence of CCP while Loon and Zhong (2014) document a decrease. Due to the nature of counterparty risk transfer under our trading strategy, the presence of CCP should not be able to explain the documented abnormal current deviations documented herein.

⁶⁷ Arora, Gandhi and Longstaff (2012) find an increase in the dealer's credit spread of 645 basis points only translates into a one basis-point decrease in the CDS premium.

aggregate margin requirement of \$5.27 billion, the annual returns are about 59.4% and 54.5%, respectively, which are abnormally high. Hence, using a reasonable level of margin requirements does not eliminate the abnormal profits documented for the matured contracts, even when the margin requirements are double for short versus long positions. These results also show that margin requirements can act as a barrier to entry since potential arbitrageurs with limited capital will be subject to the higher margins, which along with a higher cost of capital due to less diversified portfolios will render the arbitrage trading strategy tested herein unprofitable for them.

8. CONCLUSION

Based on the documented highly concentrated structure of the CDS markets, we formulate a Cournot-style oligopoly model for intermarket trading in the CDS and LCDS markets on the same reference entity. Such a model can explain the observed extensive violations of the CDS-LCDS parity relation, which holds only under competitive conditions in both markets. In turn, these violations imply time-varying and significant positive current payoffs from simulated portfolios that simultaneously take offsetting positions in CDS and the corresponding LCDS contract depending on the direction of the violation of the parity relation. We extend the oligopoly model to include proportional transaction costs. In such a case we show that the parity relation includes a no trade zone and that the transaction costs constitute a barrier to small scale entry that can be overcome by increasing the trader's scale as measured by her start-up capital.

The observed abnormal positive current payoffs cannot be explained by data imperfections, risk of future positions or limits to arbitrage such as transaction costs, illiquidity of contracts or counterparty risk, but are consistent with our oligopoly model on the dealer side in both markets. We confirm these findings with data from matured one- and three-year contracts that show uniformly positive *realized* profits of our simulated portfolios and with extensive empirical tests that reject decisively the conventional limits to arbitrage factors in favor of the competing oligopoly hypothesis. We examine the role of margins and conclude that they constitute a barrier to the entry of small scale and/or undiversified traders.

This failure of intermarket trading to equalize the spreads in the CDS and LCDS markets is analyzed theoretically and is formally documented here for the first time. Our theoretical and empirical analysis confirms the related theoretical results by Atkeson *et al* (2013) and the conjectured and anecdotal evidence by Bolton and Oehmke (2013), as well as the structure of CDS markets documented in Peltonen *et al* (2014) and Duffie *et al* (2015). Note that the CDS markets' highly concentrated nature is currently the subject of an antitrust investigation by the European Commission.^{68,69}

Our theoretical and empirical results also have regulatory implications which, however, are not clear in the absence of detailed information and intraday data on actual margins, contract depths and trading costs. For instance, the advantages of a CCP are difficult to predict a priori since its benefits from greater transparency and lower counterparty risk may be offset by the increased barriers to entry due to a greater differential between the effective margin requirements for a small subset of market participants and the remainder of the market participants. Note also that two relevant theoretical oligopoly studies reach diametrically opposite welfare implications: Shimomura and Thisse (2012) show that welfare increases with the entry of large firms, while Atkeson *et al* (2013) show that welfare improves when some large dealers are removed and smaller ones are encouraged to enter.

Examination of these factors requires access to microstructure data in the two markets. Given the importance of the CDS markets in the recent financial crisis, such a microstructure study should be the focus of future research.

⁶⁸ See http://europa.eu/rapid/press-release_SPEECH-13-593_en.htm.

⁶⁹ Note that market segmentation in derivatives markets due to institutionalized market power has been noted in at least one earlier study; see Khoury, Perrakis and Savor (2011).

Appendix: Proof of the Propositions

Proof of Proposition 1:

The proof relies on the following auxiliary result, whose proof is obvious and will be omitted. It is a specialized version of a similar result initially presented by Rothschild and Stiglitz (1970).

Lemma: Let $F(x)$ denote a concave function on the real line, and let also $x_1 > x_2$ denote two values and $p > 0$ a probability. Then any mean-preserving change $\Delta x > 0$ that reduces the distance of x_1 and x_2 increases the expectation $E_p[F(x)]$.

To prove the Proposition we now apply the lemma to the utility function $U^j(W_1^j)$ evaluated at the Cournot equilibrium y_i^{j*} , $i = 1, 2$, $j = 1, \dots, J$, $c_i^* = C_D^{i*-1}(-\sum_j y_i^{j*})$, with the following values of x_1 and x_2

$$\begin{aligned} x_1 &= W_0^j + y_1^{j*}[(1-R_1) - c_1^*] + y_2^{j*}[(1-R_2) - c_2^*] \equiv W_1^j | D \\ x_2 &= W_0^j - y_1^{j*} c_1^* - y_2^{j*} c_2^* \equiv W_1^j | S \end{aligned} \tag{A.1}$$

Assume that both y_1^{j*} and y_2^{j*} are positive, in which case $x_1 - W_0^j > 0$ and $x_2 - W_0^j < 0$ in (A.1).⁷² Then by applying the lemma it can be easily verified that the strategy of reducing unilaterally y_1^{j*} and thus raising the price c_1 above c_1^* (yielding a reduction of $-\Delta y_1^{j*}$ in the CDS volume) while simultaneously increasing unilaterally y_2^{j*} and thus reducing c_2 below c_2^* (increasing the LCDS volume by Δy_2^{j*}) and such that $\frac{\Delta y_1^{j*}}{\Delta y_2^{j*}} = \frac{(1-R_2)}{(1-R_1)}$ would increase the expectation of $U^j(W_1^j)$ and preserve the

⁷²If $x_1 - W_0^j \leq 0$ then the oligopolist's utility is inferior to the one resulting from a strategy of doing nothing.

mean $E_p(x)$. Hence, y_1^{j*} and y_2^{j*} cannot both be optimal and positive in a Cournot equilibrium. A similar proof also holds when both are assumed negative, thus proving the Proposition.

Proof of Proposition 2:

Applying the equilibrium relations (5.4) for any pair of traders (j, k) and equating the terms equal to the prices, we get,

$$\begin{aligned} (1 - R_1)[\Psi^*(j) - \Psi^*(k)] &= \frac{c_1}{Y_1 \varepsilon_D^1} (y_1^{j*} - y_1^{k*}) \\ (1 - R_2)[\Psi^*(j) - \Psi^*(k)] &= \frac{c_2}{Y_2 \varepsilon_D^2} (y_2^{j*} - y_2^{k*}) \end{aligned} \tag{A.2}$$

Suppose now without loss of generality that Y_1 is positive and assume that $y_1^{1*} \geq \dots \geq y_1^{J*}$. In such a case $j < k$ implies from the first part of (A.2) that $y_1^{j*} - y_1^{k*}$ has the opposite sign from $\Psi^*(j) - \Psi^*(k)$, which in turn implies that $\Psi^*(1) \leq \dots \leq \Psi^*(J)$. If Y_2 is also positive then the second part of (A.2) implies that $y_2^{1*} \geq \dots \geq y_2^{J*}$; this, however, is impossible, since by Proposition 1 we have $sign(y_1^j y_2^j) < 0$ and Y_2 must be negative. If, however, the signs of Y_1 and Y_2 differ the Proposition follows immediately from (A.2), QED.

Proof of Proposition 3:

Consider the case of a (5.9a) equilibrium and suppose entry is feasible at some “small” contract sizes $\varepsilon_1 < 0, \varepsilon_2 > 0$ that do not affect equilibrium in the CDS and LCDS markets respectively. In such a case we must have from (5.4) $(1 - R_1)\Psi^*(j') < c_1 - k_1$ and $(1 - R_2)\Psi^*(j') > c_2 + k_2$. It is easy to see that these two relations are incompatible with (5.11a), QED. The case of a (5.9b) equilibrium is symmetric.⁷³

⁷³Observe, however, that while (5.11ab) preclude entry in both markets, they leave open the possibility of small-scale entry in only one of the markets; in such a case, though, the entrant is no longer an arbitrageur.

Proof of Proposition 4:

The proof relies on the fact that the arbitrageurs' utilities satisfy the DARA property. We prove the result for entry in the case of a (5.9a) equilibrium for a “small” contract size $\varepsilon_1 < 0$ in market 1 only, with identical proofs for the other cases. As shown in the proof of Proposition 3, feasibility of entry for entrant $j' \notin j \in [1, J]$ implies $(1 - R_1)\Psi^*(j') < c_1 - k_1$. We need, therefore, to show that $\Psi^*(j')$

decreases or, equivalently, that $\frac{\int_0^T P^S(\tau) U^{j'}(W_1(\tau)|S) d\tau}{\int_0^T P^D(\tau) U^{j'}(W_1(\tau)|D) d\tau} = \frac{P^S}{P^D} \frac{\int_0^T U^{j'}(W_1(\tau)|S) d\tau}{\int_0^T U^{j'}(W_1(\tau)|D) d\tau}$ increases with W_0^j .

This last relation is equivalent to

$$\frac{\int_0^T U^{j''}(W_1(\tau)|S) d\tau}{\int_0^T U^{j'}(W_1(\tau)|S) d\tau} > \frac{\int_0^T U^{j''}(W_1(\tau)|D) d\tau}{\int_0^T U^{j'}(W_1(\tau)|D) d\tau} \quad (\text{A.3})$$

Since the DARA property implies $U^{j''}(W_1) > 0$ and obviously $W_1(\tau)|S > W_1(\tau)|D$ for all τ , we have $U^{j''}(W_1(\tau)|S) > U^{j''}(W_1(\tau)|D)$ and $U^{j'}(W_1(\tau)|S) < U^{j'}(W_1(\tau)|D)$, from which (A.3) follows immediately, QED.

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Table 1: Summary Statistics

This table reports the summary statistics for the full sample and sub-samples during the period from April 11th, 2008 to March 30th, 2012. The CDS and LCDS liquidity are measured by the number of distinct dealers providing quotes for each contract, respectively. The idiosyncratic volatilities are the conditional daily volatilities of individual equity return residuals by fitting the Fama-French three-factor model. Total assets equal the sum of book value of total liabilities and market value of total equities. Leverage equals book value of total liabilities divided by the total asset value. Tangible ratio equals the book value of tangible assets divided by the total asset value. The current ratio equals current assets divided by current liabilities.

	CDS Spreads	CDS Recovery Rates	LCDS Spreads	LCDS Recovery Rates	CDS Liquidity	LCDS Liquidity	Idiosyncratic Volatility	Total Asset (Thousands)	Leverage
Full Sample (No. of Observations: 68147)									
minimum	0.0027	0.0125	0.0001	0.0750	2	1	0.0053	446.51	0.0834
maximum	0.9651	0.7050	0.8984	0.9775	18	9	0.8429	295142.56	0.9857
mean	0.0461	0.3817	0.0367	0.6523	4.88	1.67	0.0237	25193.94	0.6045
median	0.0311	0.4000	0.0243	0.7000	5	1	0.0203	13565.72	0.6126
standard deviation	0.0684	0.0567	0.0482	0.1128	2.49	0.96	0.0172	37329.28	0.1842
skewness	6.7356	-1.8116	6.4265	-0.7765	0.76	1.89	10.8217	4.17	-0.2464
1 st order serial ρ (Daily)	0.9783	0.7730	0.9690	0.9273	0.6135	0.8006	0.8162	0.9904	0.9890
1 st order serial ρ (Quarter)	0.4535	0.2632	0.4125	0.3724	0.3013	0.2889	0.4439	0.5672	0.5450
Investment Grades (Above and include BBB, No. of Observations: 41327)									
minimum	0.0027	0.0722	0.0001	0.0750	3	1	0.0053	446.5	0.0834
maximum	0.9453	0.6750	0.8671	0.8500	18	9	0.6991	295142.6	0.9746
mean	0.0418	0.3809	0.0331	0.6386	5.92	1.64	0.0229	31707.0	0.5912
median	0.0252	0.4000	0.0210	0.6750	7	1	0.0194	17942.9	0.5964
standard deviation	0.0614	0.0506	0.0497	0.1152	2.24	0.98	0.0161	40757.4	0.1834
skewness	5.4439	-3.2517	6.7415	-0.6919	0.83	2.08	8.5820	3.7	-0.2199
1 st order serial ρ (Daily)	0.9659	0.7369	0.9346	0.8946	0.5843	0.7798	0.7962	0.9594	0.9709
Junk (Below BBB, No. of Observations: 11665)									
minimum	0.0028	0.0125	0.0001	0.3250	3	1	0.0054	446.51	0.0834
maximum	0.9651	0.7050	0.6253	0.8500	11	6	0.5781	257135.61	0.9794
mean	0.0543	0.3750	0.0384	0.6349	4.96	1.53	0.0240	23330.80	0.6341
median	0.0391	0.4000	0.0257	0.6500	4	1	0.0215	13154.38	0.6582
standard deviation	0.0765	0.0556	0.0416	0.1136	1.95	0.77	0.0155	38118.25	0.1939
skewness	7.5180	-2.3062	3.0163	-0.6069	0.90	1.80	8.1152	4.50	-0.4206
1 st order serial ρ (Daily)	0.8493	0.6214	0.8495	0.8364	0.3733	0.5716	0.6903	0.8697	0.8719
Not Rated (No. of Observations: 15155)									
minimum	0.0037	0.0188	0.0001	0.1000	2	1	0.0056	450.51	0.1008
maximum	0.9463	0.7050	0.8984	0.9775	2	7	0.8429	249734.43	0.9857
mean	0.0515	0.3889	0.0449	0.7030	2	1.88	0.0255	8867.08	0.6178
median	0.0363	0.4000	0.0349	0.7250	2	2	0.0218	5739.02	0.6364
standard deviation	0.0781	0.0707	0.0476	0.0882	2	1.00	0.0209	15260.94	0.1746
skewness	7.4978	-0.2131	7.5601	-1.0831	2	1.38	13.8551	11.73	-0.1909
1 st order serial ρ (Daily)	0.7864	0.7350	0.8066	0.8261	0.0000	0.6137	0.6336	0.8855	0.8320

Table 2: Summary statistics of bid-ask spreads (Unit: basis points)

This table reports the summary statistics of bid-ask spreads. The *Firm Averages* shows the average bid-ask spread for each firm during the period from January, 2nd, 2008 to November 23rd, 2012, depending upon the data availability. The *Daily Average* shows the average bid-ask spread for each day across all the available firms. The unit is basis points.

	Firm Average	Daily Average (Cross Firms)
Minimum	3.76	4.50
Maximum	283.24	93.23
Mean	35.15	26.13
Median	17.68	21.62
Standard Deviation	47.35	14.83
Skewness	3.28	1.89
Kurtosis	13.27	3.31
No. of Observations	61 Firms	1219 Days

Figure 1: Distribution of Trading Strategies with Transaction Costs

This figure depicts the distribution of trading strategies with transaction costs for the cross-sectional daily observations of the full sample during the sample period from April 11th, 2008 to March 30th, 2012.

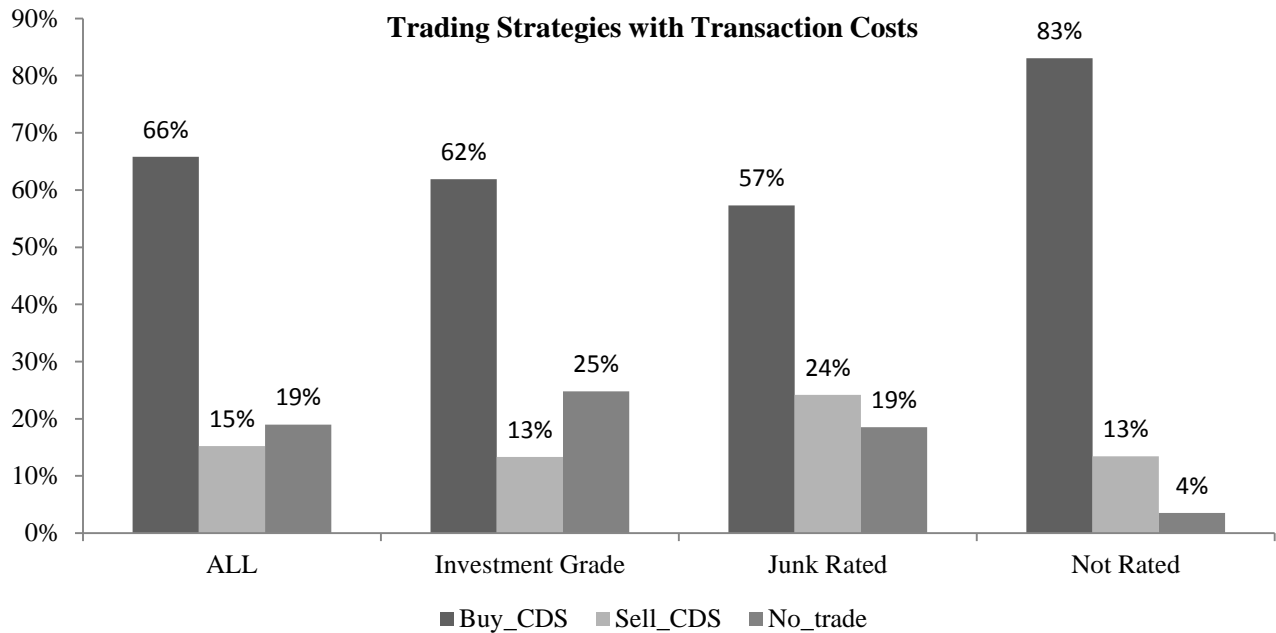


Table 3: Summary Statistics of Current Payoffs with Transaction Costs

This table reports the summary statistics of the current payoffs generated by the simulated portfolios when the CDS and LCDS parity is violated for the cross-sectional daily observations, firm daily average across the time span and index daily across all the available firms during the sample period from April 11th, 2008 to March 30th, 2012. It is assumed that the transaction costs are the same under CDS and LCDS market. The daily transaction costs come from the daily average bid-ask spread observed in the Bloomberg database with the sample firms in Table 2. Std. Dev. refers to the standard deviation.

	Minimum	Maximum	Mean	Median	Std. Dev.	Skewness	Kurtosis
Cross-Sectional Daily Observations (68147 Observations)							
Full Sample	0	1.6471	0.0338	0.0124	0.0740	8.5618	123.3978
Investment	0	1.6470	0.0266	0.0079	0.0649	11.6478	238.8615
Junk	0	0.5149	0.0292	0.0106	0.0527	3.8685	19.0626
Not Rated	0	1.2905	0.0568	0.0344	0.1015	5.7636	42.8601
Firm Daily Average Observations (120 Firm-Clause Contracts)							
Full Sample	0	0.6572	0.0413	0.0210	0.0811	5.4707	35.5509
Index Daily Observations (959 Daily Observations)							
Full Sample	0.0166	0.0855	0.0332	0.0288	0.0120	1.0370	0.3901
Investment	0.0057	0.0781	0.0257	0.0225	0.0122	1.0986	1.1091
Junk	0.0012	0.1466	0.0315	0.0264	0.0207	1.4661	2.7208
Not Rated	0.0135	0.1386	0.0562	0.0462	0.0316	0.8427	-0.4417

Table 4: Market Structure Tests

This table reports the regression results of the following restricted and unrestricted model:

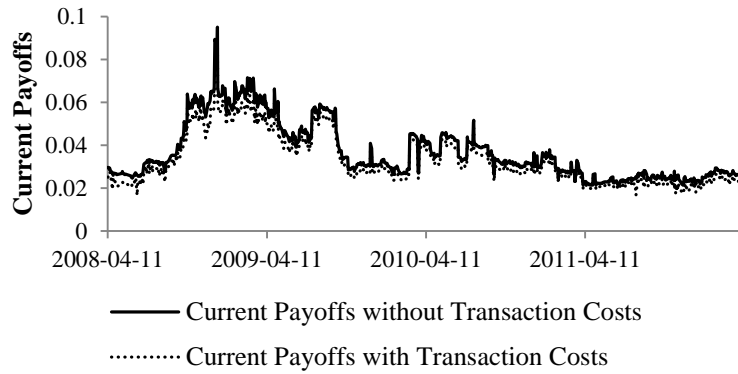
$$\begin{pmatrix} c_1 \\ c_2 \end{pmatrix}_{it} = \hat{\Phi} \begin{pmatrix} 1-R_1 \\ 1-R_2 \end{pmatrix}_{it} + \beta \left(Crisis\ Dummy * \frac{1-R_1}{1-R_2} \right)_{it} + \alpha Diff_Dealers + \varepsilon_{it}$$

Where *Crisis Dummy* equals one if the date is before April 1st, 2009 and zero otherwise. *Differ_Dealers* denotes the difference of the number of distinct dealers providing quotes in the CDS and LCDS markets. Standard errors are reported in the parentheses. N is the number of observations.

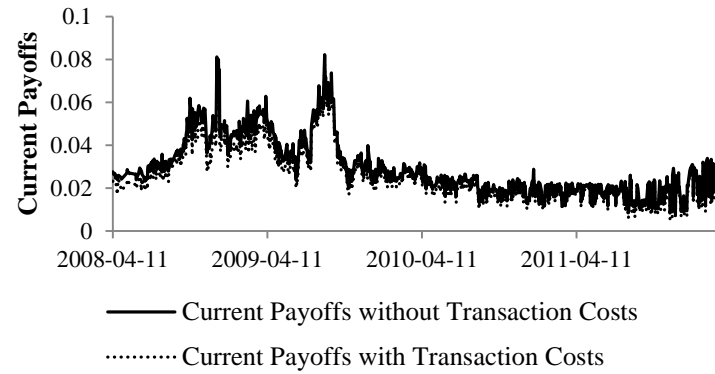
	Model (1)	Model (2)	Model (3)	Model (4)
$\hat{\Phi}$	0.6167*** (0.0132)	0.4901*** (0.0142)	0.3282*** (0.0157)	0.2509*** (0.0162)
β		0.8676*** (0.0372)		0.6993*** (0.0373)
α			0.3092*** (0.0093)	0.2827*** (0.0094)
N	68147	68147	68147	68147
R-square	3.12%	3.88%	4.65%	5.14%

Figure 2: Daily Average Current Payoffs

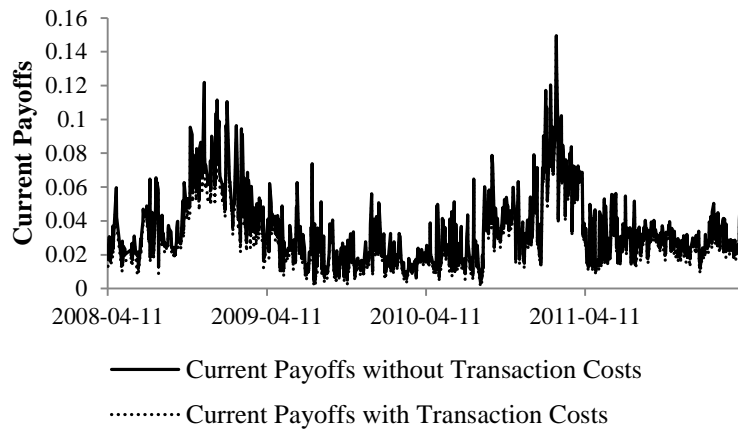
Panel A: Daily Average Current Payoffs of Full Sample



Panel B: Daily Average Current Payoffs of Investment Grades Contracts



Panel C: Daily Average Current Payoffs of Junk Rated Contracts



Panel D: Daily Average Current Payoffs of Not Rated Contracts

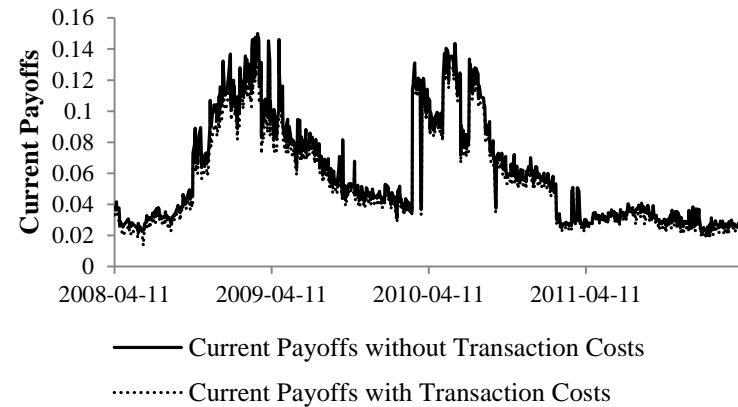


Table 5: Panel Regression with Important Events and Macro Economic Factors

This table reports panel regression results with single name fixed effects during the sample period from April 11, 2008 to March 30, 2012. The variables are the intercept (*INT*), publication of ISDA dummy (*ISDA*), the minimum number (*MIN_Q*) and difference (*DIF_Q*) of distinct dealers providing quotes for a pair of CDS and LCDS contracts, total assets (*LOGA*), current assets over current liabilities ratio (*CAL*), leverage ratio (*LEV*), tangible assets ratio (*TANG*), idiosyncratic volatility (*IDIO*), 5-year US treasury bond yields (*TB5Y*), slope of the yield term structure (*SL*), the yield spread between Aaa and Baa corporate bonds (*CBS*), and S&P 500 index returns (*SP*). Clustered standard errors are used to allow for residual autocorrelation and cross-sectional dependence as in Petersen (2009). The statistically significant coefficients are indicated by ***, ** and * for significance at the 10%, 5% and 1% significance levels, respectively. P-values are reported in the parentheses.

Variables	Full Sample	Full Sample	Investment Grades	Investment Grades	Junk	Junk	In-Crisis	In-Crisis	After-Crisis	After-Crisis
<i>INT</i>	-0.1719 (0.3410)	-0.1656 (0.3730)	-0.1994 (0.4482)	-0.1904 (0.4893)	0.0207 (0.7656)	0.0124 (0.8589)	-0.1001 (0.6996)	-0.1060 (0.6792)	0.1643 (0.4232)	-0.1379 (0.5334)
<i>ISDA</i>	-0.0019 (0.4087)	-0.0026 (0.2499)	-0.0013 (0.6809)	-0.0020 (0.5184)	-0.0031 (0.2522)	-0.0034 (0.2102)				
<i>MIN_Q</i>	-0.0005 (0.8998)		0.0009 (0.7746)		0.0021 (0.3582)		-0.0011 (0.6192)		-0.0049 (0.5442)	
<i>DIF_Q</i>		-0.0012** (0.0155)		-0.0010 (0.1068)		-0.0008 (0.1134)		-0.0006 (0.3557)		-0.0017** (0.0257)
<i>LOGA</i>	0.0156 (0.3698)	0.0149 (0.4122)	0.0194 (0.4307)	0.0186 (0.4731)	-0.0049 (0.3932)	-0.0035 (0.5470)	0.0142 (0.5620)	0.0147 (0.5436)	0.0166 (0.3945)	0.0131 (0.5424)
<i>CAL</i>	-0.0047 (0.4113)	-0.0047 (0.4269)	-0.0046 (0.4573)	-0.0045 (0.4860)	0.0003 (0.9219)	0.0003 (0.9255)	-0.0022 (0.8070)	-0.0023 (0.8047)	-0.0062 (0.3683)	-0.0062 (0.3768)
<i>LEV</i>	0.0985*** (0.0094)	0.0982*** (0.0086)	0.1308* (0.0608)	0.1310* (0.0568)	0.0716** (0.0354)	0.0742** (0.0281)	0.0830 (0.1159)	0.0820 (0.1194)	0.1039** (0.0131)	0.1036** (0.0110)
<i>TANG</i>	-0.0016 (0.9135)	-0.0005 (0.9715)	-0.0125 (0.7409)	-0.0122 (0.7496)	-0.0404*** (0.0006)	-0.0395*** (0.0006)	-0.0090 (0.8083)	-0.0084 (0.8227)	-0.0063 (0.7484)	-0.0045 (0.8227)
<i>IDIO</i>	0.3130** (0.0115)	0.3067** (0.0110)	0.3678** (0.0302)	0.3578** (0.0311)	0.2739 (0.1104)	0.2726 (0.1088)	0.1616** (0.0482)	0.1628** (0.0492)	0.3192** (0.0126)	0.3146** (0.0124)
<i>TB5Y</i>	-0.4846** (0.0343)	-0.4389** (0.0480)	-0.5533** (0.0344)	-0.4564 (0.1201)	-0.8298** (0.0456)	-0.7892* (0.0618)	1.8840*** (<.0001)	-1.8788*** (<.0001)	3.8758** (0.0307)	4.1497** (0.0212)
<i>SL</i>	1.3208*** (<.0001)	1.2571*** (<.0001)	0.8770*** (0.0037)	0.7759** (0.0134)	1.4042*** (0.0030)	1.3199*** (0.0047)	2.0266*** (0.0021)	2.0488*** (0.0018)	-3.7605** (0.0395)	-4.0868** (0.0281)
<i>CBS</i>	1.0477*** (0.0009)	1.0653*** (0.0011)	0.3099 (0.4852)	0.3448 (0.4481)	0.9636*** (0.0017)	0.9686*** (0.0015)	0.7762** (0.0272)	0.7758** (0.0253)	0.1367 (0.7947)	0.1070 (0.8523)
<i>SP</i>	-0.0026 (0.6878)	-0.0039 (0.5382)	0.0113 (0.1395)	0.0095 (0.2136)	-0.0138 (0.3922)	-0.0150 (0.3523)	0.0199** (0.0298)	0.0194** (0.0328)	0.0003 (0.9617)	-0.0030 (0.6138)
No. of Observations	68147	68147	41327	41327	11665	11665	13886	13886	54261	54261
Adjusted R ²	63.89%	63.96%	46.81%	46.89%	86.05%	86.06%	62.98%	62.99%	67.88%	67.93%

Table 6: Number of Consecutive Days with Arbitrage Profits and No Profits (Unit: Days)

This table report summary statistics for the numbers of consecutive days on which the arbitrage profits are persistent once an arbitrage profit opportunity is or is not observed according to the CDS-LCDS parity rule. First and third rows of each panel represent such opportunities.

	Min	25% Quantile	50% Quantile	75% Quantile	Max	Mean	Std	Skew
Panel A: Full Sample								
$c_{CDS} < \hat{c}_{CDS}^L$	1	1	5	24	956	51.66	130.08	3.82
$\hat{c}_{CDS}^L \leq c_{CDS} \leq \hat{c}_{CDS}^U$	1	1	3	6	539	11.21	37.90	7.48
$c_{CDS} > \hat{c}_{CDS}^U$	1	1	3	12	606	17.37	50.78	7.43
Panel B: Investment Grades								
$c_{CDS} < \hat{c}_{CDS}^L$	1	2	5	22	802	44.04	110.60	3.76
$\hat{c}_{CDS}^L \leq c_{CDS} \leq \hat{c}_{CDS}^U$	1	1	3	7	539	14.00	74.35	6.39
$c_{CDS} > \hat{c}_{CDS}^U$	1	1	3	11	598	13.35	40.16	9.29
Panel C: Junk Grades								
$c_{CDS} < \hat{c}_{CDS}^L$	1	1	4	17	956	45.37	133.56	4.68
$\hat{c}_{CDS}^L \leq c_{CDS} \leq \hat{c}_{CDS}^U$	1	1	2	5	128	6.10	14.67	6.26
$c_{CDS} > \hat{c}_{CDS}^U$	1	1	3	13	606	25.33	71.15	5.42
Panel D: No Rating								
$c_{CDS} < \hat{c}_{CDS}^L$	1	2	8	61	875	89.33	181.25	2.70
$\hat{c}_{CDS}^L \leq c_{CDS} \leq \hat{c}_{CDS}^U$	1	1	2	4	43	4.6	6.75	3.24
$c_{CDS} > \hat{c}_{CDS}^U$	1	1	4	17	380	19.53	46.04	5.62
Panel E: Crisis Period: (April, 2008 – March, 2009)								
$c_{CDS} < \hat{c}_{CDS}^L$	1	1	4	11	129	11.59	19.84	3.14
$\hat{c}_{CDS}^L \leq c_{CDS} \leq \hat{c}_{CDS}^U$	1	1	2	4	53	4.00	6.31	4.07
$c_{CDS} > \hat{c}_{CDS}^U$	1	1	2	8	89	9.61	16.34	2.67
Panel F: No Crisis Period: (April, 2009 – March 2012)								
$c_{CDS} < \hat{c}_{CDS}^L$	1	1	6	38	956	66.11	148.67	3.20
$\hat{c}_{CDS}^L \leq c_{CDS} \leq \hat{c}_{CDS}^U$	1	1	3	7	539	13.48	43.09	6.54
$c_{CDS} > \hat{c}_{CDS}^U$	1	1	4	12	606	19.07	55.40	6.88

Table 7: Diverging Ratios

This table reports descriptive statistics for the diverging ratios calculated using the overlapping windows with varying window sizes for each firm for each arbitrage profit opportunity based on violations of the CDS-LCDS parity rule. This nonparametric measure is independent of the time period since it accounts for all CDA-LCDS pairs and all the possible combinations from the total number of observations.

	Intervals	No. Obs	DR Mean	DR Median	DR STD	No. Obs	DR Mean	DR Median	DR STD
Panel A: Full Sample					Panel D: No Ratings				
$c_{CDS} < \hat{c}_{CDS}^L$	5-days	44413	46.52%	50.00%	31.57%	12451	35.75%	30.00%	32.45%
	10-days	44044	47.42%	46.67%	27.22%	12332	39.27%	37.78%	29.08%
	20-days	43342	47.93%	47.37%	24.67%	12094	42.44%	42.11%	26.75%
	60-days	40510	48.30%	48.14%	22.63%	11131	44.48%	43.39%	24.64%
$c_{CDS} > \hat{c}_{CDS}^U$	5-days	10220	52.62%	50.00%	31.30%	1998	47.33%	50.00%	32.20%
	10-days	10086	53.49%	55.56%	27.16%	1964	49.83%	51.11%	28.02%
	20-days	9815	54.55%	56.84%	24.60%	1900	53.37%	57.89%	25.71%
	60-days	8775	57.02%	59.38%	20.96%	1710	56.49%	61.58%	22.51%
Panel B: Investment Grades					Panel E: Full Sample In Crisis (April, 2008 – March, 2009)				
$c_{CDS} < \hat{c}_{CDS}^L$	5-days	25360	50.62%	50.00%	30.15%	9513	43.05%	40.00%	31.83%
	10-days	25184	50.46%	48.89%	25.76%	9513	46.01%	46.67%	27.87%
	20-days	24828	49.90%	48.95%	23.41%	9508	48.85%	49.74%	25.64%
	60-days	23464	49.83%	49.60%	21.51%	9475	59.26%	61.92%	21.29%
$c_{CDS} > \hat{c}_{CDS}^U$	5-days	5454	53.43%	60.00%	31.66%	1871	50.39%	50.00%	31.85%
	10-days	5410	53.61%	55.56%	27.59%	1866	51.65%	53.33%	28.54%
	20-days	5303	53.73%	55.79%	24.81%	1856	53.72%	56.32%	25.92%
	60-days	4923	56.59%	58.76%	20.96%	1759	59.26%	61.92%	21.29%
Panel C: Junk Grades					Panel F: Full Sample After Crisis (April, 2009 – March 2012)				
$c_{CDS} < \hat{c}_{CDS}^L$	5-days	6602	51.07%	50.00%	30.41%	34900	47.47%	50.00%	31.43%
	10-days	6528	51.06%	51.11%	25.85%	34531	47.81%	46.67%	27.03%
	20-days	6420	50.67%	50.00%	23.72%	33834	47.67%	46.84%	24.39%
	60-days	5915	49.43%	49.32%	22.20%	31035	47.66%	47.46%	22.27%
$c_{CDS} > \hat{c}_{CDS}^U$	5-days	2768	54.84%	60.00%	29.47%	8349	53.12%	60.00%	31.16%
	10-days	2712	55.91%	57.78%	25.33%	8220	53.91%	55.56%	26.83%
	20-days	2612	57.09%	58.95%	23.16%	7959	54.75%	57.37%	24.29%
	60-days	2142	58.43%	59.21%	19.56%	7016	56.46%	58.98%	20.85%

Table 8: Regression Results of Persistence and Magnitude of Arbitrage Profits

This table reports panel regression results with single name fixed effects during the sample period from April 11, 2008 to March 30, 2012. The dependent variable is the persistence of arbitrage profits measured by the number of consecutive days for which arbitrage profits persist after the first day. The independent variables are the intercept (*INT*), publication of ISDA dummy (*ISDA*), the magnitude of arbitrage profits on the first day (*Profit_TC*), total assets (*LOGA*), current assets over current liabilities ratio (*CAL*), leverage ratio (*LEV*), tangible assets ratio (*TANG*), idiosyncratic volatility (*IDIO*), 5-year US treasury bond yields (*TB5Y*), slope of the yield term structure (*SL*), the yield spread between Aaa and Baa corporate bonds (*CBS*), and S&P 500 index returns (*SP*). The persistence measure is winsorized the at 5% and 95% levels to mitigate the impact of extreme values. Clustered standard errors are used to allow for residual autocorrelation and cross-sectional dependence as in Petersen (2009). The statistically significant coefficients are indicated by ***, ** and * for significance at the 10%, 5% and 1% significance levels, respectively. P-values are reported in the parentheses.

Variables	Full	Invest	Speculative	Before Crisis	After Crisis
INT	-30.6871 (0.5046)	-7.9019 (0.8946)	-255.26 (0.1062)	88.0557 (0.3521)	-201.65** (0.0425)
ISDA	-3.4910** (0.0208)	-3.4269* (0.0618)	-2.8338 (0.4575)		
Profit_TC	250.69*** (0.0071)	361.67** (0.0108)	491.49* (0.0928)	223.89** (0.0321)	253.24** (0.0125)
LOGA	5.7295 (0.1988)	2.8684 (0.5760)	29.8725* (0.0745)	-6.8690 (0.3602)	20.3070** (0.0168)
CAL	-1.8143 (0.2984)	-4.7790*** (0.0054)	-1.3268 (0.7574)	-2.7927 (0.4345)	-3.4293** (0.0359)
LEV	18.5486* (0.0612)	14.7454 (0.1927)	31.4046 (0.5102)	2.0629 (0.9496)	27.8117 (0.1539)
TANG	-5.3762 (0.5103)	-4.1058 (0.6816)	0.2146 (0.9949)	-10.3480 (0.7514)	-2.1674 (0.8642)
IDIO	-35.7083 (0.1187)	-91.4868* (0.0727)	152.34 (0.3867)	-10.8864 (0.4826)	-78.7581* (0.0780)
TB5Y	-435.19*** (0.0001)	-447.85*** (0.0007)	-709.15 (0.1003)	9.1636 (0.9587)	2278.83* (0.0589)
SL	319.25** (0.0166)	502.05*** (0.0007)	470.56 (0.3224)	-576.77 (0.3887)	-2717.79* (0.0609)
CBS	-126.10 (0.1847)	-14.7271 (0.9200)	-622.92 (0.2692)	117.41 (0.5582)	276.25 (0.3626)
SP	11.0272 (0.6341)	7.6210 (0.7917)	27.3662 (0.6899)	15.1093 (0.5728)	-5.2962 (0.8885)
No. of Observations	2489	1597	558	613	1876
Adjusted R²	17.51%	18.78%	34.80%	19.13%	20.57%

Table 9: Portfolio Current Payoffs with Structural Model Implied CDS Recovery Rates

This table reports the results of the Generalized Method of Moments (GMM) estimation with put option implied volatilities and realized volatilities of equity, respectively, in Panel A. The details of the GMM estimation are reported in the online appendix. The summary statistics of the current payoffs of portfolios in the presence of transaction costs are reported in Panel B and C with different equity volatilities, respectively. The estimated LCDS recovery rates provided by Markit and the structural model-implied CDS recovery rates are used for the calculation of current payoffs in Panels B and C.

Panel A: Results of GMM Estimations							
	Results with Put Option Implied Volatilities of Equity			Results with Realized Volatilities of Equity			
	Asset Volatilities	CDS Recovery Rates	Sum of Squared Errors	Asset Volatilities	CDS Recovery Rates	Sum of Squared Errors	
Average across firms	0.1093	0.3532	0.0500	0.1019	0.3211	0.0406	
Standard Deviation across firms	0.0844	0.2534	0.1078	0.0794	0.2422	0.0341	
Panel B: Current Payoffs with Option Implied Equity Volatilities							
	Minimum	maximum	Mean	Median	Standard Deviation	Skewness	Kurtosis
Cross-Sectional Daily Observations (50258 Observations)							
Full Sample	0.0000	0.7174	0.0274	0.0135	0.0435	5.4270	53.3188
Firm Daily Average Observations (80 Firm-Clause Contracts)							
Full Sample	0.0001	0.1433	0.0304	0.0187	-0.0323	1.6933	2.7541
Index Daily Observations (878 Daily Observations)							
Full Sample	0.0157	0.0813	0.0274	0.0211	0.0128	1.4296	1.2226
Panel C: Current Payoffs with Realized Equity Volatilities							
	Minimum	maximum	Mean	Median	Standard Deviation	Skewness	Kurtosis
Cross-Sectional Daily Observations (50258 Observations)							
Full Sample	0.0000	0.7555	0.0283	0.0144	0.0436	5.1204	49.7035
Firm Daily Average Observations (80 Firm-Clause Contracts)							
Full Sample	0.0002	0.1435	0.0321	0.0240	-0.0323	1.4947	2.1458
Index Daily Observations (878 Daily Observations)							
Full Sample	0.0161	0.0844	0.0284	0.0223	0.0133	1.3764	1.0540

Figure 3: Term Structure of Portfolio Current Payoffs

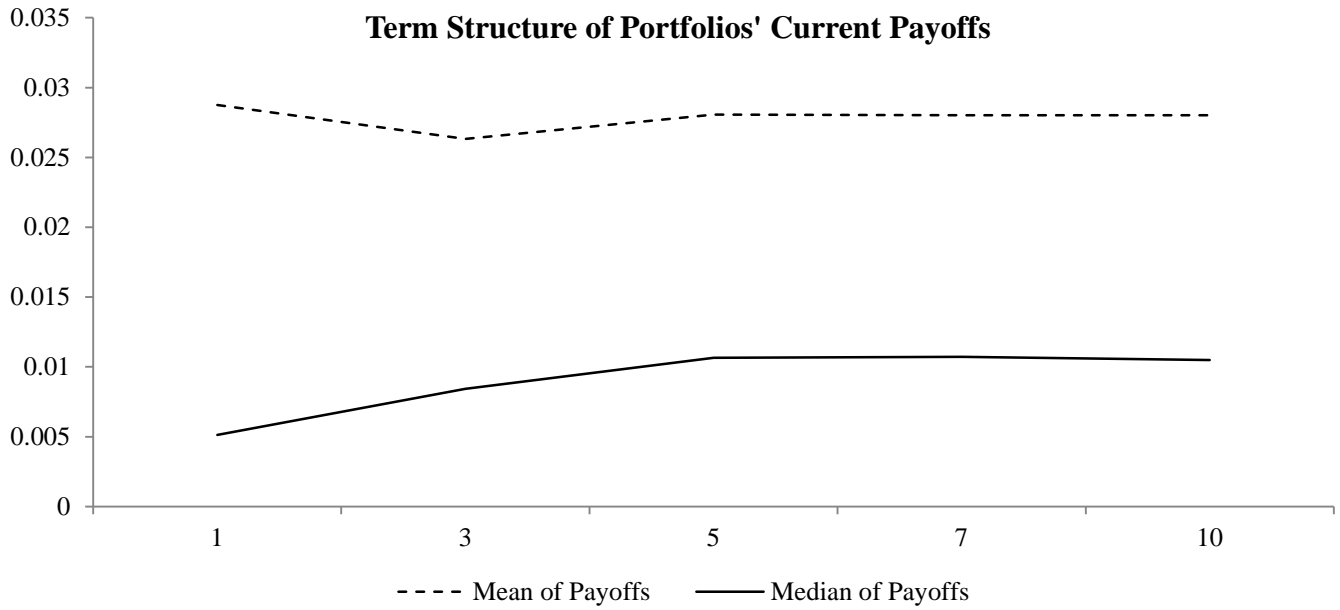


Figure 4: Distribution of Trading Strategies for different Maturities

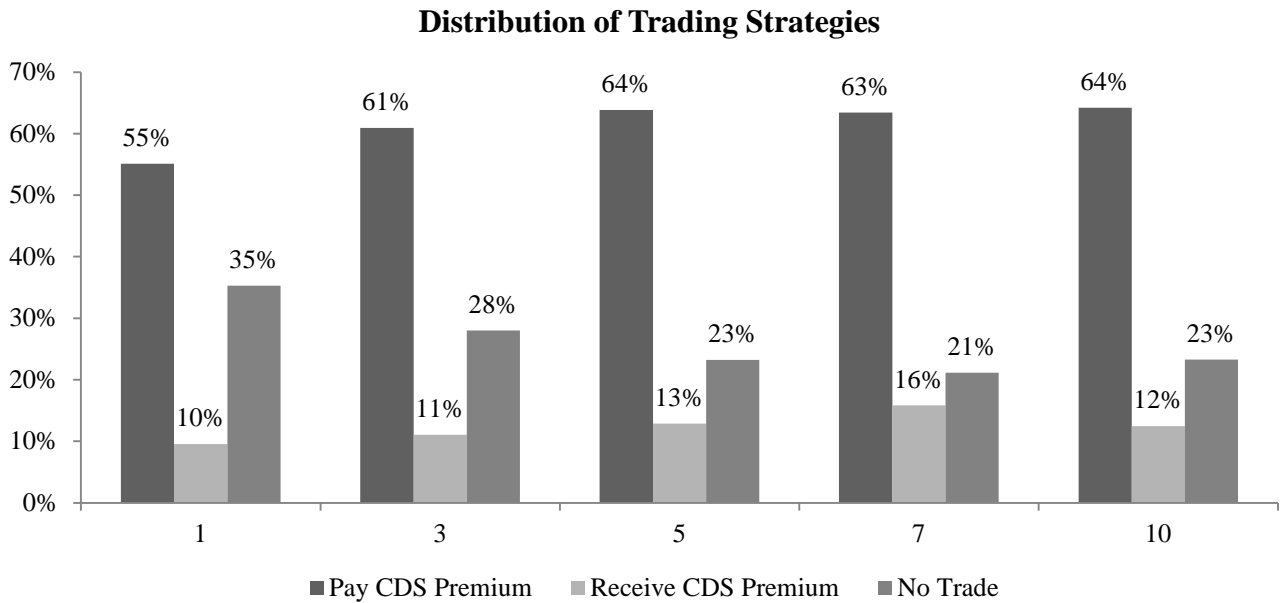


Table 10: Realized Dollar Profits for 1-year CDS/LCDS contracts for various margin requirements

This table reports the realized dollar profits (in billions of USD) for the trading strategies using 1-year CDS and LCDS contracts for various margin requirements. It is assumed that the notional amount of a CDS (or LCDS) contract is 5 Million USD. The margin requirement is proportional to the notional amount of CDS (or LCDS contracts). The cost of capital is an annual rate. Since the CDS (or LCDS) premiums are paid quarterly at 25% of the premium, it is assumed that the margin has to be deposited for 1-year in order to realize the dollar profits for each CDS-LCDS parity relation. We ignore the time value of money when we calculate the aggregated dollar profits.

Margin Requirements	Cost of Capital = 5%				Cost of Capital = 10%			
	Same for Long and Short Position		Double margin requirement for Short Position		Same for Long and Short Position		Double margin requirement for Short Position	
	Profits	Margin	Profits	Margin	Profits	Margin	Profits	Margin
0%	3.39	0	3.39	0	3.39	0	3.39	0
0.78%	3.22	3.46	3.13	5.27	3.05	3.46	2.87	5.27
1.56%	3.05	6.91	2.87	10.53	2.70	6.91	2.34	10.53
5%	2.29	22.15	1.71	33.75	1.18	22.15	0.02	33.75
10%	1.18	44.3	0.02	67.5	-1.03	44.3	-3.35	67.5