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Convertible Debt Arbitrage Crashes Revisited

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Abstract

This article examines the severity of the 2008 arbitrage crash in the convertible bond market by estimating how expensive it would have been to liquidate portfolio securities immediately. We consider whether funds actually demanded immediate liquidity or were able to delay trades. Our results indicate that the cost of immediacy was high, but that convertible bond sellers could largely avoid selling at fire sale prices. These results can be explained by dealers recognizing when trades are liquidity-motivated rather than information-based and by a shift to riskless principal trading, allowing dealers to avoid taking bonds into inventory.

I. Introduction

Intermediary asset pricing assigns a role to financial intermediaries in the determination of asset prices (He and Krishnamurthy (2013)). The availability or scarcity of capital for financial intermediaries correlates with a measurable "liquidity premium" component of asset returns. When a lack of capital prevents investors from buying underpriced securities or selling overpriced securities in sufficient quantity, the opportunity for arbitrage is limited and persistent deviations between market and theoretical prices can be observed.

As Mitchell, Pedersen, and Pulvino (MPP) (2007) note, "shocks to capital matter if arbitrageurs with losses face the prospect of investor redemptions, particularly during liquidity crises." They illustrate this point using two crisis periods: i) large convertible bond market redemptions in 2005 and ii) merger targets during the 1987 market crash. In each case, arbitrageurs switch from being liquidity providers to liquidity demanders, causing markets to dislocate for months even though seemingly profitable arbitrage opportunities were available for unconstrained investors. MPP dubbed this phenomenon "slow-moving capital."

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To better quantify this effect, Adrian, Etula, and Muir (2014), and He, Kelly, and Mian (2017) examine panels of broker-dealers and bank holding companies. They infer capital scarcity through the ex ante or contemporaneous aggregate leverage of these key intermediaries interacted with shocks to the financial system in the time series. However, intermediaries' choice of capital reserves is significantly endogenous to those intermediaries' assessment of the likelihood of a financial shock. Depending on assumptions about dealer incentives (e.g., shoring up capital ahead of an expected financial stress vs. increasing leverage due to moral hazard), this endogeneity may either overstate or understate the importance of intermediary capital to the liquidity premium.

In this article, we show new evidence from a plausibly exogenous shock to intermediary capital caused by dislocation in the convertible bond market during the 2008 Financial Crisis. As the likelihood of default increased at the prime brokerage operations of large investment (and commercial) banks, investment banks' access to rehypothecation lending was significantly limited (Mitchell and Pulvino (MP) (2012)). This caused banks to curtail lending to their prime brokerage hedge fund clients. Since convertible bond arbitrage hedge funds typically have leverage ratios of between 3:1 and 5:1, the retraction of margin lending essentially put unlevered convertible bonds back on their balance sheets. The scarcity of (attractive) financing options ultimately forced these hedge funds to liquidate convertible positions at a time when illiquidity in fixed-income markets was at historically high levels.

The purpose of this article is twofold. First, we reexamine the severity of the arbitrage crash in the convertible bond market during the fall of 2008 by estimating how expensive it would have been to immediately liquidate portfolio securities, possibly at fire sale prices. Second, we evaluate whether funds actually demanded immediate liquidity or were able to delay trades to obtain better pricing. Our results indicate that the cost of immediacy was high during the fall of 2008 but that convertible bond sellers were largely able to avoid selling at fire sale prices.

With respect to the cost of immediate liquidity, prior work by MP indicates that price quotes during the fall of 2008 reflect monthly median discounts relative to theoretical model prices of as much as 13.7%. Hendershott, Li, Livdan, and Shurhoff (HLLS) (2022) formalize this concept and define the "true" cost of immediacy (TCI) as the sum of the price discount (the difference between the theoretical price and the expected best bid price) and the expected cost of potential trade failure.[1]

We estimate that TCI respectively was 10.36% and 10.73% for in-the-money (ITM) and out-of-the-money (OTM) convertible debt during the fall of 2008. Our results are comparable to MP but are estimated differently. MP report price discounts based on nonbinding quote data, which can be interpreted as an independent estimate of the true cost of immediacy – the quoted bid price implicitly impounds the expected cost of trade failure a dealer would face when trying to locate an offsetting counterparty.

By contrast, our estimation approach requires separate estimates of the costs of failed and successful trades. Our estimates suggest that had a fund been forced to

[1]In the market for structured products, HLLS (2022) shows that failures occur frequently and can exceed 50% during stress periods.

immediately liquidate during the fall of 2008, it would have been forced to sell at fire sale prices. Whether convertible bond hedge funds actually demanded *immediate* liquidity during the fall of 2008 is an open question that we examine.

There are two explanations that could have triggered portfolio liquidations and possibly precipitated demand for immediate liquidity. The first is an investor "run" in which fund investors decide to redeem in large numbers. This first explanation is not particularly compelling because most convertible hedge funds have redemption gates. A fund that needed to liquidate a significant fraction of its portfolio to meet redemptions could raise its gate to facilitate orderly liquidation. The second possibility is the retraction of rehypothecation lending by prime brokers and the subsequent disappearance of repo financing. Even for this scenario, it is unclear why prime brokers would force funds to immediately liquidate, especially since a dealer could either: i) assist with the liquidation by attempting to locate a suitable buyer, possibly through a riskless principal trade (RPT), or ii) allow the fund to convert the bond into shares, which could then be sold in relatively liquid equity markets. While it may take several days for the conversion to fully execute, it would only require a fund to forgo any premium over its conversion value, which would be relatively small for in-the-money convertible bonds when compared to the cost of *immediate* liquidation.

Our empirical evidence suggests that funds were forced to sell in a stressed environment but were largely able to avoid fire sale prices. In other words, funds were largely able to avoid immediate liquidation. Using transaction prices, Figure 1

FIGURE 1

Monthly Median Price Discounts

Figure 1 shows the discount for both the median price (unbroken line) and maximum daily median price (dots).

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shows the median monthly price discount over the period of 2007 to 2009. We find that the maximum realized monthly median discount is 5.1%. While a 5.1% price discount is economically significant, the absolute magnitude does not rise to a level that would be considered a "fire sale" but suggests instead that some bonds were routinely sold at significant price discounts during periods of heightened illiquidity.[2] Figure 1 also plots the maximum of the daily median price discount for each month. The maximum observed median daily discount of 9.1% is quite large, indicating that *some* bonds were sold at significant price discounts.

We further examine whether dealers charge more to transact during the fall of 2008 period and how the nature of transacting changes in the face of selling pressure. We find that the effective bid–ask spread for convertible debt increased by about 8 BPS during the fall of 2008. This amount is economically small and indicates that dealers did not extract out-sized profits at the expense of liquidating hedge funds. However, they raised the incremental price discount to 2.56%, suggesting that dealers needed to lower the prices of convertible debt to find willing buyers. We attribute these findings to two factors: i) dealers understand that convertible bond trades are liquidity-motivated rather than information-based, so the impact of adverse selection is mitigated, and ii) transactions shifted to riskless principal trading, which allowed dealers to avoid taking bonds into inventory.

Concerning pre-trade transparency, there is an extensive theoretical literature that examines anonymous and, by inference, nonanonymous trading. These models highlight two significant trade-offs. On the one hand, transparency can increase liquidity by reducing adverse selection. On the other hand, pre-trade transparency reduces incentives to collect information, leading to reductions in liquidity. For example, Foucault, Moinas, and Theissen (2007) find that greater transparency reduces adverse selection and improves liquidity for securities with low levels of asymmetric information.[3]

Equity market research has shown that anonymous trading attracts informed traders (Barclay, Hendershott, and McCormick (2003)) because opacity allows traders to conceal information advantages (Bloomfield, O'Hara, and Saar (2015)). Since anonymity impedes investors' ability to make inferences about private information from order flow (Linnainmaa and Saar (2012)), trading costs tend to increase, and price impact is less (Bloomfield et al. (2015)). The model of Azarmsa and Li (2020) is the most relevant to our analysis because it explicitly models over-the-counter markets and shows that transparency improves liquidity by reducing adverse selection costs. Their theory also predicts that the bid–ask spread will be lower in nonanonymous markets, especially during periods of high uncertainty.

The second factor is riskless principal trading, wherein bondholders must bear the price risk as dealers look for investors willing to supply liquidity. The increase in the reliance on riskless principal trading that we document suggests that convertible

[2]For the subsample of "institutional" transactions (trades that exceed $1,000,000 in notional value), the maximum median monthly price discount is 4.75%. For the subsample of convertible bonds that are equity-sensitive (the ratio of stock price to conversion price > 0.65), the maximum monthly discount is 2.62%.

[3]See also Adamati and Pleiderer (1991), Benveniste et al. (1992), Madhavan (1996), Foucault, Moinas, and Theissen (2007), Rindi (2008), and Azarmsa and Li (2020).

bond arbitrage funds were willing and able to forgo immediacy to obtain smaller price discounts.

We also examine the trading behavior of large institutional investors by analyzing position data in 13-F filings, which report in Appendix F of the Supplementary Material. We find that prior to the fall of 2008, the institutional market for convertible debt was largely self-contained (i.e., purchases and sales of convertible debt largely offset each other). Consistent with the evidence discussed above, this pattern changed during 2008Q3 and 2009Q1 where net sales of $2,269 million exceeded net purchases of $1,821 million. Based on reported valuations, convertible bond prices declined in value as did the number of positions held. Despite these liquidations, the relatively small price discounts observed throughout this period indicate that portfolio losses were the result of declines in fundamental value rather than temporary liquidity shocks.

The remainder of the article is organized as follows: Section II discusses the crisis in the rehypothecation lending market and its impact on convertible bond trading during the fall of 2008. Section III discusses our hypotheses. Section IV describes the data. Section V analyzes trading activity, and Section VI explores price discounts relative to model prices. For this analysis and all subsequent analyses, we report separate results for the full sample of all bond transaction days and a volume-based propensity-matched subsample. Section VII provides an analysis of effective spreads for convertible and nonconvertible bonds. Section VIII estimates the true cost of immediacy. Section IX evaluates dealer markups on RPTs. Section X summarizes the article and offers conclusions. Appendix A of the Supplementary Material provides definitions of the variables used in our analysis.

II. The Crisis in the Rehypothecation Lending Market

A. Trading Activity and Rehypothecation Lending During the Financial Crisis

Convertible arbitrage hedge funds combine long positions in convertible securities with short positions in the convertible issuer's stock (Agarwal, Fung, Loon, and Naik (2011), Brown, Grundy, Lewis, and Verwijmeren (2012)). Hedge funds use the short-sale market to establish hedged positions that allow them to buy underpriced convertible bonds without taking on significant price risk associated with the underlying equity (Choi, Getmansky, and Tookes (2009), Choi, Getmansky, Henderson, and Tookes (2010), Brown et al. (2012), and Grundy, Verwijmeren, and Yang (2022)).[4] To amplify returns from this strategy, hedge funds also employ leverage provided by their prime brokers, frequently at ratios of 3:1 to 5:1.

Prime brokers can offer financing rates slightly higher than those paid on U.S. Treasuries by requiring hedge funds to post collateral (securities and cash),

[4]Three approaches have been used to examine the effects of hedge fund purchases of newly issued convertibles: one focuses on short interest in the stock of the issuer (Choi, Getmansky, and Tookes (2009), De Jong, Dutordoir, and Verwijmeren (2011)); another examines aggregate fund flows into convertible arbitrage hedge funds (Choi et al. (2010), Verwijmeren and Yang (2020)); the third considers actual hedge fund participation levels (Brown et al. (2012)).

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which the prime broker is then given permission to post as collateral for a loan to the prime broker by a third party lender ("rehypothecation"). MP describe rehypothecation lending and the associated regulatory constraints in great detail. They estimate that hedge funds owned $4.7 trillion of securities at the end of 2007, financed by approximately $2.8 trillion in debt from their prime brokers.[5]

Following the bailout of Bear Stearns and the bankruptcy of Lehman Brothers, financing costs for investment banks soared to unprecedented levels (relative to the risk-free rate) as repo financing dried up for almost all risky collateral. MP attribute much of the illiquidity in fixed-income markets, particularly convertible securities and high-yield debt, to the disappearance of repo financing.

Recognizing potential solvency problems at banks, rehypothecation lenders began to pull back. According to MP, banks used any available rehypothecation lending to finance their balance sheets, while, at the same time, cutting off hedge fund prime brokerage clients. Based on conversations with prime brokerage officials, MP note that "forced deleveraging [of hedge fund clients] was immediate in many cases, resulting in portfolios being liquidated." Moreover, nonstressed hedge funds began to sweep excess cash out of their accounts, which further mitigated investment banks' ability to engage in rehypothecation lending based on high-quality collateral.

Graph A of Figure 2 illustrates trading activity for convertible bonds from Jan. 2007 to Dec. 2009 for investment and speculative grade classifications. The figure represents the number of days during the month in which individual bonds had buyer and seller-initiated transactions. One can observe the sharp decline in trading activity during the fall of 2008 for convertible debt. Note also that convertible debt markets do not regain pre-crisis trading activity levels in the year after the crisis.

Graph B of Figure 2 shows that nonconvertible debt markets also experienced declines in trading volume, but not nearly as large on a relative basis compared to convertible debt. Additionally, trading activity in nonconvertible debt reverts to pre-crisis levels within 6 months.

The dramatic declines in trading volume during the fall of 2008 depicted in Figures 2 (Graph A) and 3 are consistent with the theoretical model of Dugast, Üslü, and Weill (2022). Their model shows that trading in OTC markets is motivated by risk-sharing demands and the trading capacities of market participants. The authors then posit that trading capacities reflect "differences in funding constraints, access to collateral pool, risk management technology, or trading expertise."[6] In their

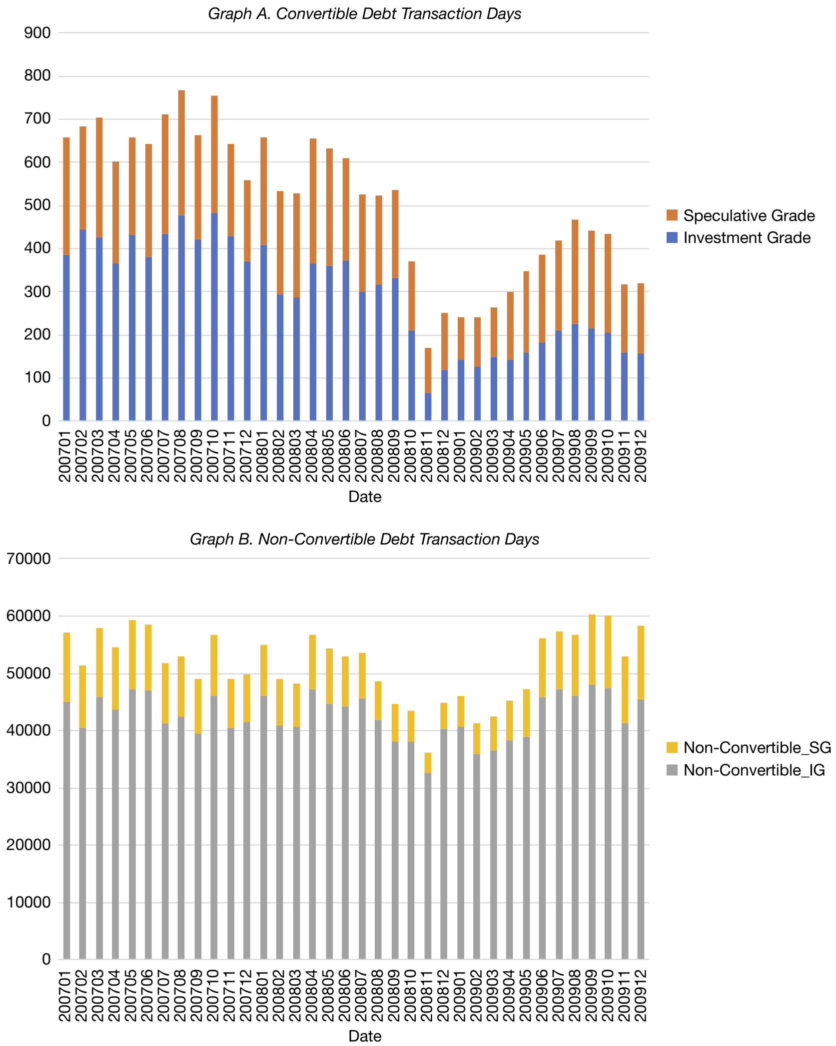
[5]Those authors estimate that "Assuming that hedge funds hold all of their assets in margin accounts and that prime brokers rehypothecate the maximum 140% of customer debit balances pursuant to Rule 15c3-2, prime brokers are able to rehypothecate $3.9 trillion of securities and secure $2.8 trillion of debt on an off-balance sheet basis."

[6]Dugast et al. (2022) show that, depending on trading capacities, market participants optimally participate in OTC and centralized markets. The model assumes that "trade size in the OTC market is an increasing function of both counterparties' capacities, while in the centralized market, it is an increasing function of a bank's own trading capacity." When banks have heterogeneous trading capacities and homogeneous risk-sharing needs, their Proposition 6 shows that gross OTC volume is increasing in trading capacity.

FIGURE 2

Transaction Days for Convertible and Nonconvertible Debt

Figure 2 illustrates trading activity from Jan. 2007 to Dec. 2009. Graph A represents the number of days on which there were transactions. Graph B shows the same for nonconvertible debt.



model, gross trading volume is an increasing function of trading capacity, implying that an exogenous shock to trading capacity, like that associated with the retraction of rehypothecation lending, would lead to market-wide decreases in trading volume like those experienced in the fall of 2008. This evidence is prima facie in line with the idea of a freeze—hedge funds could not immediately find suitable buyers at reasonable prices, or if they had to trade immediately, prices would reflect fire sale discounts.

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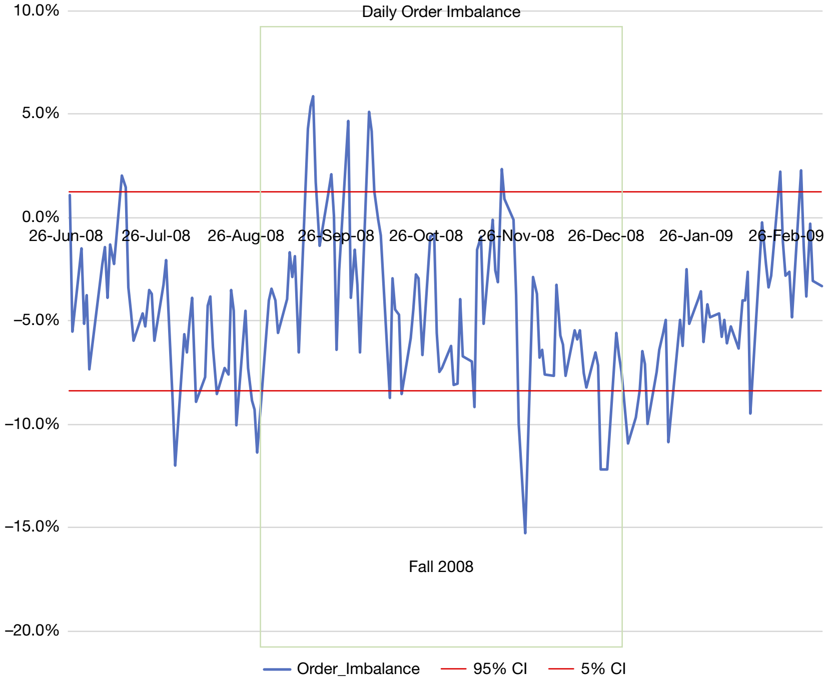
FIGURE 3

Daily Order Imbalance for Convertible Debt

Figure 3 shows the daily order imbalances from Aug. 2008 to Jan. 2009.



B. Forced Selling and Fire Sales

When markets become illiquid due to significant selling pressure, fire sales may occur as assets trade below their intrinsic values. Shleifer and Vishny (1992) motivate fire sales in the context of corporate asset sales, where they assert that firms in similar industries experience financial distress at similar times. In their model, similar firms become distressed because they are operationally similar and are likely to be forced to sell assets to satisfy financial commitments simultaneously. Because the firms most likely to purchase those assets may also be liquidity constrained, it becomes difficult to find buyers willing to pay intrinsic value, causing assets to sell at discounts. Coval and Stafford (2007) extend this reasoning to equity markets and find that funds with large outflows tend to sell the same securities to meet redemption requests, creating price pressure in the securities held in common by distressed funds.[7] If investors anticipate liquidity-induced losses, they may preemptively redeem shares ahead of other investors, further depressing prices.

MP provide evidence consistent with the fire sale explanation. They report a spike in quoted price discounts for equity-sensitive convertibles during the fall of

[7]Coval and Stafford (2007) then develop a flow-based metric that identifies fire sales based on unusually high trading volume across multiple funds and report quarterly cumulative abnormal returns of 7.9% in quarters when mutual funds sell assets in a fire sale.

2008. The median price discount peaked at 13.7% on Dec. 4, 2008. They conjecture that convertible bond markets became illiquid as it took time for "slow-moving capital" to take advantage of significant pricing discrepancies. Consistent with abnormal selling pressure during the fall of 2008, Figure 3 shows that daily order imbalances corresponding to seller-originated convertible bond trades were indeed abnormally high for many days during the fall of 2008, particularly in September.

C. Price Discounts Based on Quotes Versus Transaction Prices

A limitation of the MP analysis is that it relies on estimates of price discounts based on quotations rather than actual transaction prices. Since bond dealers are not obligated to transact at quoted prices, quotes may reflect a dealer's *interest* in trading a particular bond, not an *actionable* commitment to trade at that price. Given the illiquid nature of fixed-income markets, price quotes can be interpreted as a dealer's initial estimate of the cost of obtaining immediate liquidity as opposed to the actual cost a seller would have to pay if the dealer had time to find a willing counterparty. An open question then is whether convertible bond hedge funds demanded immediate liquidity and sold convertible positions at quoted prices (the slow-moving capital explanation), or whether they were able to liquidate in a more orderly fashion. We answer this question by estimating the "true" cost of immediacy – the cost that investors would pay if they had to liquidate positions immediately – and comparing it to the "actual" costs investors paid when they sold convertible debt.

We use the valuation model of Tsiveriotis and Fernandes (TF) (1998), which fully accommodates holder and issuer optionalities, and which is also used by Ammann, Kind, and Wilde (2003), Chan and Chen (2007), Loncarski, ter Horst, and Veld (2009), Brown et al. (2012), and Lee, Verwijmeren, and Wang (2023). Tsiveriotis and Fernandes use a binomial-tree approach to model the stock price process and decompose the total value of a convertible bond into an equity component and a straight debt component. To address possible instabilities associated with lattice-based valuations, we apply a number of robustness checks and arbitrage constraints and find no evidence of unstable price estimates.[8] As MP note: "none of the results presented in this article is model dependent, and even the simple straight bond plus warrant valuation technique can illustrate the enormous change in convertible cheapness during the crisis period." Consequently, we do not believe that our choice of a pricing model can plausibly explain our findings.

III. Hypothesis Development

A. Convertible Bond Trading Frequency During the Fall of 2008

Convertible bond hedge funds forced to liquidate entire portfolios must sell many securities that trade infrequently. When coupled with an illiquid market,

[8]Zabolotnyuk, Jones, and Veld (2010) show that the TF model performs substantially better than the Brennan and Schwartz (BS) (1980) finite-difference model. When comparing model prices to market prices, they report mean absolute deviations of 1.94% for the TF model versus 3.73% for Brennan Schwartz finite-difference model.

Dugast et al. (2022) show that the rate of trading is expected to slow down as dealers search for parties willing to provide liquidity. We predict that the number of days between trades for all bonds will increase in the fall of 2008 and that the effect will be more pronounced for convertible debt due to hedge fund-induced selling pressure.[9]

Hypothesis 1. Since bond markets became illiquid during the fall of 2008, the amount of time between trades is expected to increase for all bonds. The incremental effect will be stronger for convertible bonds due to hedge fund liquidations.

B. Convertible Bond Trade Pricing During the Fall of 2008

We next explore how much it costs to trade convertible debt when markets are stressed. There are two related ways to estimate trading costs: i) the ex ante "true" cost of immediacy and ii) the realized price discount (the difference between actual and model prices). Since we estimate price discounts from *successful* trades, realized trading costs abstract from the expected cost of a trade failure.

The wave of seller-initiated trades experienced in the fall of 2008 resulted in significant selling pressure as investors tended to be on one side of the market. Dealers responded by lowering prices to attract buyers. Suppose dealers did not need to provide immediate liquidity. In that case, it is possible that dealers may have been able to avoid charging fire sales by searching for suitable nonintermediary investors and connecting their "slow-moving capital" to assets. Due to the exogenous nature of the shock in the fall of 2008, we expect the average price discount to increase to reflect higher search costs. However, the ability to avoid immediate liquidation and the fact that trade seller identities are known to the dealer may prevent convertible debt from being sold at fire sale prices.

Hypothesis 2. In a market where counterparties are known to the dealer and the underlying reasons for net selling pressure are based on exogenous factors unrelated to asymmetric information, convertible bond prices may reflect higher than average price discounts to reflect relatively high search costs. The ability to avoid immediate liquidation and the mitigation of adverse selection will prevent them from selling at fire sale prices.

The bid–ask spread reflects dealer concerns about adverse selection, search costs, and inventory carrying costs. Therefore, it is difficult to disentangle these three components' incremental impact empirically. The same economic considerations that lead to predictions about price discounts are similar for bid–ask spreads, that is, higher search costs and higher inventory carrying costs are expected to widen spreads, while less adverse selection has the opposite effect (tighter spreads).

[9]In a "normal" market, the marginal (informed) investor will trade on new (or accumulated) information only if the trade is expected to yield a profit net of transaction costs. The cost of trading then constitutes a threshold that must be exceeded before a trade will occur. All else equal, a bond with high transaction costs will have less frequent price moves and more ZERO_DAYS, where we define ZERO_DAYS as the number of days that elapse between days where there was at least one buy and one sell order (see Lesmond, Ogden, and Trzcinka (1999)).

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Our next prediction recognizes that trading levels were abnormally low and inventory costs were high during the fall of 2008. Based on Azarmsa and Li (2020) and Dugast et al. (2022), exogenous selling caused by hedge fund liquidations (which reduces adverse selection costs for dealers) was specific to convertible debt, while search costs increased for all *bonds.*

Hypothesis 3. In a market where investors are net sellers, dealers are expected to widen the effective bid–ask spread to compensate for, among other things, higher search costs. In a market where counterparties are known, and the underlying reason for net selling pressure is based on exogenous factors that are specific to convertible debt (like the fall of 2008), effective bid–ask spreads for convertible debt will be less than those for nonconvertible debt due to fewer concerns about adverse selection.

If a hedge fund was required to liquidate its portfolio immediately during the fall of 2008, we expect the cost of immediacy to increase. As explained in more detail in Section VII, our formulation of TCI has two components: the probability of trade failure and the price discount. Since HLLS estimate the price discount using the average daily *bid* price and we use the volume-weighted average of the daily bid and ask prices, we add the effective half-spread to conform our estimates to HLLS. During the fall of 2008, we expect to see increases in both components. Trade failures are more likely as it becomes increasingly harder to find liquidity providers. Price discounts increase to attract buyers, and spreads increase to compensate dealers for higher search costs.

Hypothesis 4. An exogenous shock to arbitrage capital liquidity is expected to increase the true cost of immediacy.

C. Riskless Principal Trading During the Fall of 2008

For simplicity, we assume that investors have two choices when trading a bond. They can request immediate liquidity forcing the dealer to take the bond into inventory, or they can agree to a RPT in which they wait for the dealer to find a suitable counterparty. After a dealer has found another counterparty for the RPT, the dealer trades with both counterparties simultaneously. Additionally, RPTs reduce dealer adverse selection and inventory cost concerns because only the client faces price risk as the dealer searches for someone to take the opposite side of the trade.

Our next hypothesis recognizes that dealers' balance sheets were distressed during the fall of 2008 and could not extend balance sheet liquidity to hedge funds. Therefore, liquidating hedge funds may have been offered i) unacceptably low bid quotes from dealers in exchange for immediacy or ii) the option of a more fair price if the hedge fund could wait a short time for the dealer to arrange a RPT.[10] Since hedge funds have a fiduciary obligation to their clients to liquidate portfolios in the least costly manner, we predict that they will rely more on RPTs to avoid possible fire sale pricing. This duty also reinforces the predictions of Hypothesis 1 in that

[10]In private conversations with bond market participants, the typical amount of time to complete a riskless principal trade is less than a day.

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increased reliance on RPTs will tend to slow down the trading rate as dealers search for counterparties willing to provide liquidity, possibly as a RPT.

Hypothesis 5. Given that convertible hedge funds were liquidating portfolios during the fall of 2008, we predict that convertible bond trades are more likely to be executed as RPTs given the large number of illiquid bonds that must be sold.

Hypothesis 5 can also help explain why our results differ from those of MP. If hedge funds optimally chose RPTs, they may be able to transact at prices that reflect lower discounts and therefore avoid paying dealer "fire-sale" quotes. While this is an empirical issue, an affirmative finding would demonstrate the importance of using transaction prices to explain what happened rather than basing inferences on a "but-for-world" that did not occur.

In the subset of pre-arranged trades (RPTs), dealers do not bear the cost of adverse selection or carrying inventory. Instead, they act as a broker that has already arranged both buyer and seller. For these trades, a change in spreads is more clearly driven by a change in dealer search costs. We next consider whether bond dealers can extract greater per-trade profits during the fall of 2008. For this analysis, we focus on RPTs because it is possible to estimate dealer markups.

Hypothesis 6. Given that convertible hedge funds were liquidating portfolios during the fall of 2008 but still wanted to avoid fire sale pricing, we predict that convertible bond trades are more likely to be executed as RPTs, and dealers will charge higher markups.

IV. Data

Our analysis uses the merged Enhanced TRACE data and Mergent data. The Enhanced TRACE data includes price, yield to maturity, trade size, and a buy-sell indicator for each corporate bond transaction that involves a dealer (more than 99% of the market). The Mergent data provides bond-specific information that includes: time to maturity, the promised rate, the offering yield, and other important contractual features. The sample period starts Jan. 2, 2007, and ends Dec. 31, 2009. We select this period because it spans the fall of 2008.

A. Data Filters

The initial sample is constructed with the Enhanced TRACE data by applying a number of data filters described in Bessembinder, Maxwell, and Venkataraman (2006) and Dick-Nielson (2009) that eliminate observations that reflect data entry errors. We dropped 439,269 canceled trades and 311,920 trades that were corrected. We also deleted 18,196 trades that occurred on weekends and holidays, were duplicates, had a missing bond identifier, or had prices of less than $1.00. We then eliminate 9,709 "reversal" transactions, where a reported price differs from the preceding and following prices by more than 15%. Provided there are at least five trades on the day, we then eliminate 274,442 trades that exceed an upper bound of 1.075 times the daily *median* price or fall below a lower bound of 0.925 the daily *median* price. We drop 19,862 trades that had a daily price change that exceeds 50%. This results in a sample of 29,974,315 observations.

We augment the enhanced TRACE data with Mergent Bond data, which provides additional information about bond ratings, contractual information (e.g., conversion price and time to first call), and offering information (e.g., amount sold and initial pricing). This allows us to apply several additional filters. We eliminate 39,858 trades that were executed after the bond's maturity date, 16,377 trades that had trade sizes that were less than the bond's par value, 7,715 trades where trade volume exceeds the notional amount of bonds outstanding, 362,840 nonconvertible bonds that had prices that exceed a theoretical upper bound (the sum of promised interest and principal payments), and 467,634 trades of nonconvertible bonds where the bond is selling at a discount but the current yield is less than the offering yield. After applying these filters, the final sample contains 29,079,891 observations.[11]

B. Issue Characteristics and the Pricing of Traded Bonds

Using the Mergent database, we obtain the details of the structure of each convertible bond issue – the conversion ratio, coupon rate, maturity date, call dates, and put dates. Call features can be complex and may involve resetting the call price annually over the life of the bond. We also adjust the conversion price for stock splits.

We value convertible debt using the Tsiveriotis-Fernandes (1998) model. The inputs include the underlying stock price, stock return volatility, the issuer credit spread, and the term structure of interest. Stock prices come from the CRSP database. Stock return volatility is estimated as the annualized daily standard deviation using the past 200 trading-day stock returns. For the credit rating, we use contemporaneous estimates of the S&P credit rating. When a rating is unavailable, we estimate a credit rating using an ordered probit model that takes accounting and stock market data as inputs.

Table 1 provides summary statistics describing issue characteristics and bond market prices. Panels A–C of Table 1 characterize the full sample and subsamples of convertible and straight debt, respectively. Straight and convertible debt constitute 96.41% and 3.59% of all bond trades over the sample period. For the convertible debt subsample, 69.9% of all convertible bonds are classified as ITM, or "equity-sensitive."[12] We provide variable definitions in the Appendix.

Panel A of Table 1 reports that the bonds have an initial average time to maturity of 11.8 years (median = 10.0 years), an average coupon rate of 5.81%, and a corresponding offering yield of 5.92%. Over the sample period, bonds sell at discounts to par value (93.75). Discount pricing is consistent with the current yield exceeding the offering yield (8.05% vs. 5.92%). Note that the median price of 98.75 reflects a relatively small discount to par value.

In Panel B of Table 1, we show that convertible debt tends to have longer maturities (16.95 years) with lower coupon rates (2.79%) and offering yields

[11] It is likely that these additional filters reflect the misreporting of CUSIPs.

[12] A convertible bond is classified as ITM if it has a delta (the partial derivative of the convertible bond with respect to the underlying stock price) that exceeds 0.65.

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TABLE 1

Summary Statistics for Issue Characteristics and Pricing

In Table 1, we report the mean, standard deviation, 1-percentile, 25-percentile, median, 75-percentile, and 99-percentile of the variables. Panel A reports statistics for the full sample. Panels B and C report statistics for convertible debt and straight debt, respectively. Sample period is Jan. 2, 2007, to Dec. 31, 2009.

Variables	Mean	Std. Dev.	1%	25%	Med.	75%	99%
Panel A. All Securities (28,926,419 Transactions for 31,569 Bonds)							
COUPON_RATE	5.87	1.76	0.00	5.00	5.85	6.88	10.38
OFFERING_YIELD	5.92	1.66	2.25	5.15	5.81	6.65	9.51
YEARS_TO_MATURITY	11.81	8.74	2.00	6.00	10.00	11.00	40.00
PRICE	93.75	16.77	15.02	92.10	98.75	102.07	117.17
CURRENT_YIELD	8.05	7.67	1.16	5.04	6.14	8.01	57.52
Panel B. Convertible Debt (1,067,450 Transactions for 922 Bonds)							
COUPON_RATE	2.79	1.83	0.00	1.50	2.75	3.88	8.00
OFFERING_YIELD	3.31	1.60	0.50	2.00	3.25	4.25	7.75
YEARS_TO_MATURITY	16.95	10.71	3.00	7.00	20.00	20.00	60.00
PRICE	90.54	19.00	23.59	83.50	94.65	101.37	117.17
CURRENT_YIELD	6.97	9.09	1.16	2.37	4.13	7.44	57.52
Panel C. Straight Debt (27,858,969 Transactions for 30,647 Bonds)							
COUPON_RATE	5.96	1.70	0.0	5.1	5.88	6.9	10.4
OFFERING_YIELD	5.98	1.71	3.1	5.2	5.84	6.7	9.7
YEARS_TO_MATURITY	11.56	8.58	2.0	6.0	10.00	10.0	35.0
PRICE	94.86	15.10	21.3	93.2	99.00	102.2	117.0
CURRENT_YIELD	7.69	6.43	1.4	5.1	6.12	7.9	46.6

(3.31%). Compared to straight debt investors, convertible bond investors accept lower coupon rates on the offering date because they also receive a valuable warrant on the underlying firm's equity. Although convertible bonds have longer maturities than straight debt, their effective maturities are much shorter because many convertibles include call provisions that allow issuing firms to force conversion.[13] The mean and median convertible bonds sell at a discount to par value over the sample period.

Panel C of Table 1 shows that straight debt has a mean maturity of 11.56 years and a mean coupon rate of 5.98%. The mean and median prices to par value, respectively, are 94.86 and 99.00.

C. Characteristics of Trade Size

Table 2 provides summary statistics that characterize trade size for the full sample (Panel A), the subsample of convertible bond trades (Panel B), and the subsample of straight debt trades (Panel C). Panel A reports significant skewness in trade size. The mean daily trading size is $456,296 with a median of $25,000. The reported skewness is caused by a relatively small number of days with very large trades (the 99-percentile trade is $10,000,000). Using the buy-sell indicator in the Enhanced TRACE data set, we also estimate trade size for trades that buyers

[13]The optimal call policy is to call bonds once their warrant is in-the-money because it removes a valuable call option from bondholders, and many firms follow this optimal policy (Grundy and Verwijmeren (2016)). Lewis and Verwijmeren (2011) document that 72.14% of convertible bonds contain call provisions. Grundy and Verwijmeren (2018) show that the fraction of convertible bonds containing call provisions decreases over time.

TABLE 2

Summary Statistics for Trade Size

In Table 2, we report the mean, standard deviation, 1-percentile, 25-percentile, median, 75-percentile, and 99-percentile for trade size, buyer-originated trade size, and seller-originated trade size. Panel A reports statistics for the full sample. Panels B and C report statistics for convertible debt and straight debt, respectively. Sample period is Jan. 2, 2007, to Dec. 31, 2009.

Variables	Mean	Std. Dev.	1%	25%	Med.	75%	99%
Panel A. All Securities							
ALL_TRADES	456,296	1,424,215	1,000	10,000	25,000	100,000	10,000,000
BUYER_ORIGINATED_TRADE	406,468	1,334,850	1,000	10,000	25,000	93,000	8,635,000
SELLER_ORIGINATED_TRADE	520,227	1,528,879	1,000	10,000	25,000	105,000	10,000,000
Panel B. Convertible Debt							
ALL_TRADES	1,104,078	2,010,319	1,000	8,000	65,000	1,500,000	10,000,000
BUYER_ORIGINATED_TRADE	1,150,790	2,024,646	1,000	10,000	100,000	1,500,000	10,000,000
SELLER_ORIGINATED_TRADE	1,060,555	1,995,896	1,000	6,000	50,000	1,200,000	10,000,000
Panel C. Straight Debt							
ALL_TRADES	433,621	1,396,000	1,000	10,000	25,000	100,000	10,000,000
BUYER_ORIGINATED_TRADE	382,595	1,301,000	1,000	10,000	25,000	76,000	8,075,000
SELLER_ORIGINATED_TRADE	500,430	1,509,000	1,000	10,000	25,000	100,000	10,000,000

or sellers originated. The mean trade size of buy and sell orders, respectively, are $406,468 and $520,227.

Panels B and C of Table 2 show that the mean convertible debt trade ($1,104,078) is substantially bigger than the average straight debt trade ($433,621). The disparity between the median trades ($65,000 vs. $25,000) is smaller but still economically significant.

D. Identifying RPTs

We measure the prevalence and cost of RPTs with dealers using an algorithm to identify RPTs over the entire sample period. Our algorithm identifies sets of trades that could open and close a trader's position for exactly offsetting positions within specific time periods. We group trades by security CUSIP and then sort by date and execution time-stamp. For all N trades in each CUSIP/date pair, we determine if the trade T_{n-1} is i) in the opposite direction as trade T_n (i.e., dealer buying from a customer or another dealer vs. dealer selling), ii) has the same quantity/notional value, iii) occurs within 1 minute, and iv) has not already been marked in a previous iteration as part of an existing set of RPTs in our data set. If the pair of trades satisfies these conditions, we record the markup, time-in-inventory, notional one-sided volume, and whether the trades are "institutional-sized" (>$100 K notional). If these conditions are not satisfied, we do nothing to mark those trades and iterate to examine the next transaction.[14]

[14]As Harris (2015) observes, "this indirect approach for identifying RPTs fails to identify RPTs when the dealer accesses two or more quotes to fill a customer order, or when a dealer simultaneously fills several customer orders when trading against the same quote. The latter situation may occur when a broker-dealer, who has investment discretion over several client accounts, trades for many accounts simultaneously. The method also may fail to identify RPTs if the sample selection criteria used to construct the TRACE sample exclude one or more reports of trades involved in a RPT." However, using a

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Because TRACE delays reporting corporate bond transactions by 15 minutes, alternative measures of RPTs, as in Choi and Huh (2017), broaden the time window (our condition (iii)) to 15 minutes and allow more than two consecutive trades to be included in a round trip transaction. We construct two more measures to evaluate the robustness of our riskless principal trading results. The first, "BROAD_RPT," expands the time window to 15 minutes. The second follows a modification of the model in Li and Schurhoff (2019) and allows a longer-horizon trade where the dealer holds the position in inventory over multiple days. Unlike Li and Schurhoff (2019), our model of roundtrip trade looks at when a dealer opens and closes a trading position rather than when a bond leaves the possession of a customer until it is repurchased by another customer (potentially passing through multiple dealers). In this final class of "LIFO" inventory trades, our condition (iii) is widened to 366 calendar days or just over 1 year.

Although we allow multiple buys and multiple sells to form a "roundtrip" of trades within the RPT, they must be consecutive (i.e., all $k+1$ trades $[n-k,n]$ must belong to the RPT roundtrip). We determine whether trade T_n is part of a roundtrip by recursing backward, starting with $k=1$, and check: i) whether trade T_{n-k} is already associated with an RPT of this type, ii) whether trade T_{n-k} is within 15 minutes of trade T_n, and iii) if the sum of trades $[n-k,n]$ equals 0. We calculate the bid–ask spread, markup, and so forth as before for trade roundtrips that satisfy these conditions. Suppose a set of trades is associated with multiple trade types. In that case, we only consider the trade roundtrip to be of the shortest-duration type (e.g., if the trades that comprise a trade roundtrip are classified as both BROAD_RPT and LIFO, we would only consider it to be of type BROAD_RPT).

Table 3 presents summary statistics for our three trade types (RPT, BROAD_RPT, and LIFO). Mean realized dealer markups are higher for BROAD_RPT trades (97.22 BPS) than RPT trades (69.15 BPS), and higher still for LIFO trades (130.83 BPS). At the same time, mean dollar volume per trade is highest for BROAD_RPT and LIFO trades ($984,711 and $944,992, respectively), and economically much lower for RPT trades exited within one minute ($120,511).

V. Trading Activity

This section evaluates trade frequency during the fall of 2008. The analyses we present below report results for the full sample and a propensity-matched subsample based on expected volume. To identify the propensity matches, we select the five nonconvertible bonds with the closest mean expected volume over the pre-fall 2008 period for each convertible bond.[15] Expected volume is calculated as the fitted value from this ordinary least squares equation:

sample of bond dealer transactions, Calomiris, Glosten, and Munyan (2017) determined that this algorithm is highly effective at identifying RPTs.

[15]If a nonconvertible bond matches with more than one convertible bond, it is only included in the sample once.

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TABLE 3

Summary Statistics on Trade Roundtrips Identified Using TRACE

Table 3 reports summary statistics for the types of roundtrip trades identified using the enhanced TRACE data set. When looking at consecutive trades in a single CUSIP, we identify sets of transactions which could potentially represent a dealer's roundtrip trading in and out of a position in that bond. Pairs of consecutive trades occurring within 1 minute that offset each other and involve a dealer's trading with at least one customer are labeled riskless-principal trades, or "RPT." Using a broader definition of pre-arranged trades, where a set of consecutive trades concluding within 15 minutes and involving at least one customer trade are labeled type "Broad_RPT." Finally by extending the time up to 1 year before the trading position must be closed, we record additional sets of trades with label "LIFO." We do not allow any transactions to belong to more than 1 set of trades, meaning our definitions of Roundtrip Types are mutually exclusive. For each set of roundtrip trades, we record the realized markup that could have been earned if a single dealer was responsible for the roundtrip trade, as well as the time duration of the roundtrip (time in inventory) and one-sided dollar notional volume per trade.

Roundtrip Type	RPT (<1 Minute)	Broad_RPT (1–15 Minutes)	LIFO (15 Minutes–1 Year)
Panel A. Entire Sample			
N	1,846,396	192,304	257,257
Markup ($ per $100 traded)			
Mean	0.69147	0.97222	1.30832
Std. dev.	0.68266	1.10386	1.53608
Time in inventory (minutes)			
Mean	0.061	3.87882	462.2369
Std. dev.	0.17951	3.92136	1,681.61
Dollar volume per trade			
Mean	120,511	984,711	944,992
Std. dev.	1,049,599	4,255,558	3,297,704
Panel B. Outside Q4 2008			
N	1,617,002	172,163	231,416
Markup ($ per $100 traded)			
Mean	0.69891	0.95777	1.25947
Std. dev.	0.68299	1.08486	1.44754
Time in inventory (minutes)			
Mean	0.06361	3.88268	471.379
Std. dev.	0.18308	3.92819	1,719.64
Dollar volume per trade			
Mean	122,336	981,499	967,691
Std. dev.	1,079,317	5,159,510	3,390,388
Panel C. During Q4 2008			
N	229,394	20,141	25,841
Markup ($ per $100 traded)			
Mean	0.63903	1.09572	1.74613
Std. dev.	0.67801	1.24785	2.12423
Time in inventory (minutes)			
Mean	0.04258	3.84583	380.37
Std. dev.	0.15070	3.86239	1,289.22
Dollar volume per trade			
Mean	107,645	1,012,166	741,712
Std. dev.	809,632	5,001,902	2,297,366

$$\text{(1)} \qquad \ln\left(\text{VOL}_{jt}\right) = \alpha + \beta_1 \ln(\text{VOL}_{i,t-1}) + \beta_2 \ln(\text{MKT\_VOL}_t) + \beta_3 \ln(\text{MKT\_VOL}_{t-1}) + \theta X_{jt} + \gamma_j + \varepsilon_{jt},$$

where VOL_{jt} is the sum of buyer (VOL_{jt}^A) and seller (VOL_{jt}^B) initiated volume for bond j at week t, MKT_VOL_t is aggregate weekly market volume (the sum of VOL_{jt} across all bonds at week t), γ_j is a bond fixed effect, and ε_{jt} is the residual. X_{it} is a set of additional control variables that includes the bond rating, bond maturity, the Treasury bond spread, the credit spread, and the first lag of Zero Days. Detailed

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variable definitions are in the Appendix. We report model estimates in Table IA.1 in the Supplementary Material.

A. Trade Frequency Statistics

Table 4 reports summary statistics for the entire sample period and the fall of 2008. The mean daily notional trading volume for a convertible bond is $9.340 million (Panel A), which is more than double the mean nonconvertible bond trading volume of $4.046 million (Panel C). The results for the fall of 2008 are qualitatively similar. That is, conditional on a bond trading that day, the amount of trading volume is comparable to the surrounding period.

We also find that bond-specific order imbalance (buying vs. selling to dealers) is close to 0 over the entire sample period and during the fall of 2008 across all security types. This result is not surprising because dealers prefer to maintain flat books (large order imbalances are expected to reverse). The mean order imbalance for convertible debt increases substantially in the fall of 2008 (0.351) relative to the entire sample period (0.059). Consistent with Figure 3, the order imbalance estimates for convertible debt indicate that trades tended to be seller-initiated.

In the spirit of Lesmond et al. (1999), we calculate the number of days (ZERO_DAYS) that elapse between "trade events." A trade event is defined as a day when there is at least one buy and one sell order. This metric captures the notion

TABLE 4

Daily Summary Statistics Aggregated by Security Type

Panels A and C of Table 4 report aggregate daily volume, order imbalance metrics, and the number of days that elapse between trading of a particular bond (Zero Days) for a bond over the full sample period (Jan. 2, 2007, to Dec. 31, 2009) and the fall of 2008 (Sept. 2008 to Dec. 31, 2008, for convertible debt (Panel A) and nonconvertible debt (Panel C). Panels B and D report the price discount, the effective spread, bond ratings, and the Treasury term spread over the full sample period (Jan. 2, 2007, to Dec. 31, 2009) and the fall of 2008 (Sept. 2008 to Dec. 31, 2008, for convertible debt (Panel B) and nonconvertible debt (Panel D). We report the mean, standard deviation, and median by individual bond and trading day.

	Full Sample			Fall of 2008		
Variables	Mean	Std. Dev.	Median	Mean	Std. Dev.	Median
Panel A. Trading Activity Metrics for Convertible Debt						
AGGREGATE_VOLUME ('000 s)	9,340	22,718	2,236	8,637	16,713	2,000
ORDER_IMBALANCE	0.059	1.952	0.003	0.351	1.778	0.068
AGGREGATE_DAILY_IMBALANCE	−0.119	0.092	−0.122	−0.030	0.105	−0.051
ZERO_DAYS	4.15	14.10	1.00	5.18	17.09	1.00
Panel B. Trading Cost, Bond Rating, and Macroeconomic Metrics for Convertible Debt						
PRICE_DISCOUNT (%)	0.524	6.706	0.397	2.131	5.890	1.230
EFFECTIVE_SPREAD (%)	0.198	0.299	0.077	0.292	0.377	0.132
BOND_RATING	7.54	5.22	9.00	7.65	4.89	8.00
TREASURY_TERM_SPREAD (%)	1.31	1.19	1.63	2.00	0.18	2.01
Panel C. Trading Activity Metrics for Nonconvertible Debt						
AGGREGATE_VOLUME ('000 s)	4,046	31,350	229	3,872	52,680	184
ORDER_IMBALANCE	−0.126	1.319	−0.036	−0.023	1.220	0.000
AGGREGATE_DAILY_IMBALANCE	−0.123	0.091	−0.124	−0.018	0.102	−0.019
ZERO_DAYS	4.43	15.32	1.00	5.05	16.68	1.00
Panel D. Trading Cost, Bond Rating, and Macroeconomic Metrics for Nonconvertible Debt						
PRICE_DISCOUNT (%)	0.363	4.033	0.263	1.424	4.578	0.653
EFFECTIVE_SPREAD (%)	0.275	0.337	0.141	0.375	0.408	0.215
BOND_RATING	6.90	3.47	6.00	6.38	3.40	6.00
TREASURY_TERM_SPREAD (%)	1.56	1.21	1.78	2.03	0.20	2.04

that the marginal (informed) investor will trade on new (or accumulated) information only if the trade yields a profit net of transaction costs. The cost of trading then constitutes a threshold that must be exceeded before a trade will occur. All else equal, a bond with high transaction costs will have less frequent price moves and more days with zero trading.

Panels A and C of Table 4 report that the mean number of days between trades of the same bond (ZERO_DAYS) is 4.15 days for convertible bonds, versus 4.43 days for nonconvertible bonds. During the fall of 2008, the mean number of zero days increased to 5.18 days for convertible bonds and 5.05 days for nonconvertible bonds, which indicates that convertible bond trading slowed down in the fall of 2008 by an average of 1.03 days.

B. Trading Frequency Regression Results

To better understand trade determinants, we estimate a survival model that employs the following difference-in-difference (DID) specification:

$$\text{(2)} \quad \ln\left(\text{ZERO\_DAYS}_{jt}\right) = \alpha + \beta^{\text{CON}}\text{I\_CON}_j + \beta^{\text{FALL}}\text{I\_F\_2008}_t + \beta^{\text{FALL\_CON}}\text{I\_F\_2008}_t \times \text{I\_CON}_j + \theta X_{jt} + \varepsilon_{jt},$$

where X_{jt} is a set of additional control variables, and the hazard function is assumed to be distributed Weibull. The control variables address variation in bond characteristics (delta, bond rating, years to maturity), macroeconomic conditions (Treasury term spread), and aggregate trading volume.

Panels B and D of Table 4 report summary statistics for key explanatory variables by bond type. The effective spreads and Treasury term spread increased in the fall of 2008 relative to the Full Sample period.

We report the results of the Zero Days regression in Table 5. The first model represents transaction days for the full sample and the second model is based on the expected volume propensity-matched subsample. Convertible bonds tend to trade at approximately the same rate as nonconvertible debt outside of the fall of 2008

TABLE 5

Survival Model for Days Between Trade Events

Table 5 reports the results from a parametric survival model of the number of days between trades where the hazard rate is assumed to be distributed Weibull. ZERO_DAYS is the dependent variable. The first regression uses the full sample and the second only includes observations from an expected volume propensity-matched subsample. Each regression is a DID model that includes a set of control variables. To simplify interpretation of the coefficients, all continuous variables are standardized by subtracting the mean and scaling by its standard deviation (i.e., *z*-scored). The robust standard errors control for heteroscedasticity and are calculated using a Huber/White/sandwich estimator.

	Full Sample			Expected Volume Propensity-Matched Sample		
Variables	Coeff.	*t*-Stat.	*p*-Value	Coeff.	*t*-Stat.	*p*-Value
I_CON	−0.0314	−0.50	0.621	−0.0327	−0.47	0.639
I_F_2008	−0.0339	−6.32	0.000	−0.0676	−2.75	0.006
I_F_2008 × I_CON	−0.1208	−1.77	0.076	−0.1195	−1.39	0.166
DELTA	0.0082	1.34	0.179	0.0414	1.60	0.109
BOND_RATING	0.1044	63.33	0.000	0.1031	15.99	0.000
YEARS_TO_MATURITY	−0.0220	−13.79	0.000	0.0550	8.75	0.000
TREASURY_TERM_SPREAD	−0.0228	−15.41	0.000	−0.0123	−2.05	0.040
AGGREGATE_VOLUME	0.0105	4.36	0.000	0.0541	5.67	0.000
No. of obs.	1,415,115			76,191		

(the coefficient estimate $\beta^{\text{I\_CON}}$ is insignificantly different from 0). Consistent with Hypothesis 1, trading in the fall of 2008 slows down for nonconvertible ($\beta^{\text{I\_F\_2008}} = -0.0339$) and convertible debt ($\beta^{\text{I\_F\_2008}} + \beta^{\text{I\_F\_2008} \times \text{I\_CON}} = -0.1547$). The finding that $\beta^{\text{I\_F\_2008} \times \text{I\_CON}}$ is negative and marginally different from 0 supports the hypothesis (Hypothesis 1) that hedge fund selling causes greater disruptions in the convertible bond market. This result should be interpreted with caution because, even though the point estimates are similar, the coefficient $\beta^{\text{I\_F\_2008} \times \text{I\_CON}}$ is insignificantly different from 0 for the propensity-matched subsample.

To put these estimates into context, the hazard rate associated with the Weibull survival model takes the following form:

$$h(t, X_{j,t}) = h_0(t)\lambda(X_{j,t}), \tag{3}$$

where $h_0(t) = pt^{p-1}$ is the baseline hazard and $\lambda = e^{\beta\prime X_{j,t}}$ is the relative risk associated with the covariates. The estimated value of the "shape" parameter (p) is 0.7462, which indicates that the baseline hazard rate is monotonically decreasing. The associated probability of going t days until the next trade event is calculated as:

$$S(t, X_{j,t}) = e^{-\lambda(X_{j,t})t^p}. \tag{4}$$

To characterize the marginal impact on trading activity during the fall of 2008, we calculate the mean days to a trade event,

$$\text{DTE}(X_{j,t}) = \int_0^{\infty} S(\tau, X_{j,t})\, d\tau,$$

and the median days to a trade event, $\text{DTE50}(X_{j,t})$, is defined as the time $\hat{t}$ such that $S(\hat{t}, X_{j,t}) = 0.50$.

Table 6 reports summary statistics for estimates of $\text{DTE}(X_{j,t})$ and $\text{DTE50}(X_{j,t})$ for convertible and nonconvertible debt transactions inside and outside the fall of 2008. We find that the average DTE for convertible debt outside the fall of 2008 is 3.33 days. As predicted, this estimate increased during the fall of 2008 (3.33 + 0.80 = 4.13). A t-test of the difference in sample means across time periods rejects the null of no difference (t-stat. = 35.08, p-value < 0.001). Nonconvertible debt also traded less frequently in the fall of 2008. The average additional mean time to a trade event is 0.28 days (3.80–3.52). An analogous t-test of the difference in sample means across time periods rejects the null of no difference (t-stat. = 202.53, p-value < 0.001).

To test whether convertible debt traded relatively slower than nonconvertible debt during the fall of 2008, we calculate the difference in the mean days to a trade event between convertible and nonconvertible debt on day t,

$$\Delta\text{ADTE}_t = \text{Avg}\left(\text{DTE}_{j,t}^{\text{CON}}\right) - \text{Avg}\left(\text{DTE}_{j,t}^{\text{NONCON}}\right). \tag{5}$$

Consistent with Hypothesis 1, we find that the increase in the time to a trade event for convertible debt during the fall of 2008 is 0.78 days longer than the increase for nonconvertible debt. A t-test of the difference in the sample means of ΔADTE_t across time periods rejects the null of no difference (t-stat. = 37.12,

TABLE 6

Expected Days to a Trade Event

Table 6 reports calculated values of the mean and median days to a trade event for convertible and nonconvertible debt for trade events inside and outside the fall of 2008. It also reports the results of three *t*-tests of the equality of the means: i) *t*-Test 1: difference in mean days to a trade event for convertible debt inside and outside the fall of 2008, ii) *t*-Test 2: difference in mean days to a trade event for nonconvertible debt inside and outside the fall of 2008, and iii) *t*-Test 3: difference between the mean days to a trade event for convertible and nonconvertible debt inside and outside the fall of 2008.

	Full Sample		Expected Volume Propensity-Matched Sample	
	Convertible Debt	Nonconvertible Debt	Convertible Debt	Nonconvertible Debt
Panel A. Summary Statistics for the Mean and Median Days to a Trade Event				
Inside the fall of 2008				
No. of obs.	1,007	135,316	819	4,357
Mean days to trade event, DTE	4.13	3.80	4.30	4.56
Median days to trade event, DTE50	2.12	1.95	2.26	2.40
Outside the fall of 2008				
No. of obs.	12,329	1,266,463	12,517	58,498
Expected days to trade, DTE	3.33	3.52	3.33	4.08
Median days to trade, DTE50	1.71	1.80	1.75	2.15
Panel B. Tests of Equality of the Average of DTE				
t-Test 1	0.80	35.08	0.97	36.48
t-Test 2	0.28	202.52	0.48	55.57
t-Test 3	0.78	37.12	0.95	39.22

p-value < 0.001). We obtain similar results for the median days to a trade event. The results for the propensity-matched subsample also are similar.

VI. Trading Costs: Price Discounts

This section analyzes the determinants of price discounts and quantifies the size of the incremental price discount in the fall of 2008. The percentage price discounts (PD_{jt}) for convertible and nonconvertible debt are estimated as the relative difference between the model price estimated using the TS model (MODEL_{jt}) and the mean of the daily value-weighted ask (A_{jt}^{VOL}) and bid ((B_{jt}^{VOL})) prices, that is,

$$\text{PD}_{jt} = \frac{\text{MODEL}_{jt} - P_{jt}}{P_{jt}}, \tag{6}$$

where $P_{jt} = \left(A_{jt}^{\text{VOL}} + B_{jt}^{\text{VOL}}\right)/2$. We estimate price discounts for all bonds because both convertible and nonconvertible bonds would be expected to trade at discounts to theoretical prices when illiquidity is high. While we expect *all* bonds to trade at price discounts during the fall of 2008, we predict that nonconvertible debt will trade at economically smaller but still significant price discounts. This is confirmed in Panels B and D of Table 4.

Panel B of Table 4 reports that the mean price discount for convertible debt increased from 0.524% to 2.131% in the fall of 2008. Over the same period, the mean price discount for nonconvertible debt increases from 0.363% to 1.424% (Panel D). The smaller change for nonconvertible debt is consistent with our earlier observation that this market was not under as much stress as the convertible market.

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These significant increases in price discounts demonstrate the importance of calculating the price discounts associated with all trades. As noted in Section II.C, the TS model uses a binomial-tree approach for the underlying stock price process that decomposes the total value of a convertible bond into equity and straight debt components. A principal benefit is it fully accommodates holder and issuer optionalities, such as conversion and call features. By setting the conversion price to an arbitrarily high value (1.0×10^9), we can use the same model to calculate prices for nonconvertible debt. This forces the equity component to have 0 value while preserving all of the bond's contractual features, including call provisions. Although we have previously explained why do not expect the TS to have systematic biases, using the same pricing model for convertible and nonconvertible debt implicitly controls for any such biases.

We estimate a DID regression for the daily price discount (PD_{jt}) that includes bond-specific fixed effects as:

$$\text{(7)} \quad \text{PD}_{jt} = \alpha + \beta^{\text{FALL}} \text{I\_F\_2008}_t + \beta^{\text{FALL\_CON}} \text{I\_F\_2008}_t \times \text{I\_CON}_j + \theta X_{jt} + \gamma_j + \varepsilon_{jt},$$

where X_{jt} is the same control variables as the survival model and γ_j is a bond fixed effect. The fixed effects absorb the coefficient for convertible debt (I_CON).

Table 7 reports that the cost of trading nonconvertible bonds in the fall of 2008 increased by 0.607% (β^{FALL}). Consistent with there being a more severe disruption in the convertible debt market (Hypothesis 2), convertible bonds reflected an even higher incremental price discount of 2.555% ($\beta^{\text{FALL}} + \beta^{\text{FALL\_CON}} = 0.607\% + 1.948\%$). As we make clear in the next section, where we estimate the true cost of immediacy, sellers of convertible debt accepted substantial price discounts.

Table 7 indicates that ITM convertibles ($\beta^{\text{DELTA}} < 0$) with lower credit quality ($\beta^{\text{RATING}} < 0$) trade at smaller discounts. Price discounts also are lower when Treasury rates ($\beta^{\text{TREAS\_SPRD}} < 0$) are expected to rise and when illiquidity is low ($\beta^{\text{AGG\_VOL}} < 0$).

TABLE 7

Price Discount Regressions

Table 7 reports the results the estimation results from a price discount regression that includes bond-specific fixed effects. The regression is a DID model that includes a set of control variables. To simplify interpretation of the coefficients, all continuous variables are standardized by subtracting the mean and scaling by its standard deviation (i.e., *z*-scored). Standard errors are clustered by individual bond.

	Full Sample			Expected Volume Propensity-Matched Sample		
Variables	Coeff.	*t*-Stat.	*p*-Value	Coeff.	*t*-Stat.	*p*-Value
I_F_2008	0.6070	13.28	0.000	0.7880	3.83	0.000
I_F_2008 × I_CON	1.9480	2.77	0.006	1.9120	2.63	0.009
DELTA	−0.6790	−2.04	0.041	−2.8750	−2.20	0.028
BOND_RATING	−2.7380	−12.73	0.000	−1.4500	−2.40	0.017
YEARS_TO_MATURITY	0.0930	0.19	0.850	7.2200	2.78	0.006
TREASURY_TERM_SPREAD	−0.1710	−4.06	0.000	0.3660	1.66	0.097
AGGREGATE_VOLUME	−0.0310	−5.13	0.000	−0.0780	−2.00	0.046
No. of obs.	1,427,214			76,892		
Adj. R^2	0.037			0.021		
No. of bond CUSIPs	18,573			1,074		

The results for the propensity-matched subsample are similar and display no substantive differences. For example, the point estimates for the incremental price discount associated with convertible bond trading during the fall of 2008 for the Full Sample and the propensity-matched subsample are 1.948% and 1.912%, respectively.[16]

VII. Trading Costs: Effective Spreads

The slow-moving capital theory asserts that securities sell for less than intrinsic value when three conditions are met: i) markets become illiquid, ii) investors are net sellers, and iii) frictions impede investor access to arbitrage capital. In such a market, locating counterparties willing to take the other side of a potential trade becomes harder. This increases search costs and, all else equal, customers would be expected to transact at prices below fundamental value and face wider bid–ask spreads.

Traditional models of the bid–ask spread (see Huang and Stoll (1997)) argue that adverse selection and order processing costs are important determinants.[17] An open question is the relative importance of these factors in a market where an exogenous liquidity shock largely drives trading.

Fixed income markets are unique because their microstructure potentially mitigates adverse selection concerns. Specifically, bonds trade in over-the-counter "voice" markets, and dealers know trader identities.[18] To the extent that dealers can infer that convertible bond trades are motivated by external factors unrelated to the quality of the underlying securities (i.e., the revocation of rehypothecation-based lending), dealers understand that forced selling is unrelated to adverse selection. In this situation, dealers would be expected to lower their fees by narrowing spreads.[19] These offsetting considerations result in a tension between search costs

[16]To evaluate the robustness of our findings, Appendix B of the Supplementary Material reports results for price discount regressions using three different subsamples: i) a sample that excludes all retail trades (transactions with a notional value less than $100,000), ii) a sample that only includes institutional sized trades (transactions with a notional value that exceeds $1,000,000), and iii) a sample that only includes equity sensitive trades (stock price/conversion price exceeding 0.65). All of the results are qualitatively similar to those reported in this section. We also provide results for return-based factor models similar to Harris and Piwowar (2006). Again, the results are qualitatively similar to those reported above. Supplementary Material provides a more detailed description of these tests and results.

[17]Dick-Nielsen and Rossi (2016) find that the costs of obtaining immediacy increase significantly when bonds are excluded from bond indices. They attribute their findings to dealer disincentives to hold inventory related to the passage of the "Volcker Rule."

[18]There is a limited amount of electronic trading in fixed-income markets, but it is a relatively small fraction of total volume, also in 2008.

[19]This prediction is based on the Admati and Pfleiderer (1991) theory of "sunshine trading" where investors who need to make a large transaction announce their intentions, increasing the willingness of counterparties to provide them with liquidity. Bessembinder,Carrion, Tuttle, and Venkataraman (2016) develop this model further and demonstrate that even with a monopolistic liquidity provider, liquidity will improve when that liquidity provider knows investors' trading intentions are not driven by fundamental information. Helwege, Huang, and Wang (2014) discuss the difficulties of disentangling components of bond spreads. Using a paired sample approach that filters out credit risk, they conclude that standard liquidity proxies do a poor job and that the incorporation of the same proxies for other bonds issued by the firm as well as those for bonds of other firms can significantly improve the explanatory power.

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and adverse selection, and it is unclear which effect will dominate. Our empirical tests allow us to consider whether, on net, search costs or adverse selection are more important.

A. Measurement of Effective Spreads

Researchers have employed various approaches for estimating trading costs in fixed-income markets. Some apply techniques initially developed for equity markets (Schestag, Schuster, and Uhrig-Homburg (2016)). Others are specific to stylized features of bond trading (Lesmond et al. (1999), Edwards, Harris, and Piwowar (2007), Dick-Nielson (2009), Dick-Nielson, Feldhutter, and Lando (2012), and Feldhutter (2012)). Schestag et al. (2016) compare different methodologies and conclude that most of the transaction cost metrics used in prior empirical research, including the measure of effective spread used in this article, "capture variations in transactions costs on both a time-series and cross-sectional level."

Our measure for effective spreads follows Hong and Warga (2000) and Chakravarty and Sakar (2003). It is a daily measure that exploits the buy/sell indicator in the Enhanced TRACE data set. Since broker sells are reported at the ask and broker buys at the bid, the effective spread for bond j on day t (EFF_SPRD_{jt}) is calculated as the difference between the daily volume-weighted ask price (A_{jt}^{VOL}) and bid price (B_{jt}^{VOL}) scaled by the corresponding bid–ask midpoint.

(8) $$\text{EFF\_SPRD}_{jt} = \frac{A_{jt}^{\text{VOL}} - B_{jt}^{\text{VOL}}}{\left(A_{jt}^{\text{VOL}} + B_{jt}^{\text{VOL}}\right)/2}.$$

A limitation of our effective spread estimate is that we need at least one buy and one sell on the same day.[20] Our approach is similar to Bessembinder, Kahle, Maxwell, and Xu (2009) who argue that value-weighted trade prices produce the most powerful event study test statistics. Unlike Bessembinder et al. (2009), who exclude bonds that do not trade on 10 of the past 20 days, we retain all trades regardless of size. The 10 trading day requirement is not relevant for calculating effective spreads because our measure of effective spreads is unaffected by non-trading days.[21]

Panel D of Table 4 reports that the mean effective spread for nonconvertible debt is 27.5 basis points (BPS) and has a standard deviation of 33.7 BPS. The effective spread for convertible debt is 19.8 BPS (Panel B), which is 7.7 BPS less. Table 4 also provides estimates during the fall of 2008. Panel B reports that the mean effective spread for convertible bond trades is 9.4 BPS (29.2–19.8) higher during the fall of 2008.

[20]Edwards et al. (2007) note that relative to their approach, which uses all bond trades, our restriction eliminates a large number of bond days from the sample. Harris and Piwowar (2006) propose an alternative transaction cost model that regresses bond returns on several exogenous factors and an ad hoc functional form for transaction costs. Edwards et al. (2007) extend this model by adding factors that proxy for duration and credit risk.

[21]Our results are robust to the exclusion of trades of less than $10,000.

B. Effective Spread Regression Results

We estimate the incremental cost of trading convertible debt relative to straight debt during the fall of 2008 using a panel regression that includes bond fixed effects:

$$\text{(9)} \quad \text{EFF\_SPRD}_{jt} = \alpha + \beta^{\text{FALL}} \text{I\_F\_2008}_t + \beta^{\text{CON}} \text{I\_CON}_t + \beta^{\text{FALL\_CON}} \text{I\_F\_2008}_t \times \text{I\_CON}_j + \theta X_{jt} + \gamma_j + \varepsilon_{jt} + \epsilon_{jt},$$

where the vector X_{jt} represents a set of control variables that include aggregate volume, order imbalance metrics, bond rating metrics, the Treasury bond term spread, a γ_j is a bond fixed effect.

Equation (9) is a DID model that we use to test Hypothesis 3. The coefficient estimates allow us to determine whether: i) the costs of trading straight debt are different during the fall of 2008 (β^{FALL}), ii) the costs of trading convertible debt during this period are different from straight debt ($\beta^{\text{CON}} + \beta^{\text{FALL\_CON}}$), and iii) the costs of trading convertible debt during the fall of 2008 period are different from trading convertible debt outside this period ($\beta^{\text{FALL}} + \beta^{\text{FALL\_CON}}$).

Table 8 presents evidence that supports Hypothesis 3. Based on model 1 in Panel A of Table 8, the cost of trading any bond during the fall of 2008 increased by 7.7 BPS. This increase is in line with Boehmer et al. (2013), who also find that trading costs increase during that period. Table 8 also shows that the incremental effective spreads are the same for convertible and nonconvertible debt during the fall of 2008; $\beta^{\text{FALL\_CON}}$ is not statistically significant. The lack of significance implies that the convertible bond-specific liquidity shock did not worsen round-trip trading costs for convertible bonds.[22]

C. Analysis of Large Order Imbalances

This subsection considers the possibility that trades executed when order imbalances are relatively large may cost more to execute. Model 2 in Panel B of Table 8 indicates that it is less costly to trade on days when the aggregate order imbalance across all securities is large. The specification includes the variables I_BIG_BUY and I_BIG_SELL. I_BIG_BUY is an indicator variable that takes the value 1 if the order imbalance for bond j on day t is negative and in the top 10-percentile of the daily order imbalance distribution across all securities. I_BIG_SELL is an indicator variable that takes the value 1 if the order imbalance for bond j on day t is positive and in the top 10-percentile of the daily order imbalance distribution across all securities. Consistent with the explanation that larger orders are harder to execute, we find that, on days when aggregate order imbalance is high, the effective spread for nonconvertible debt widens by 8.2 BPS (I_BIG_BUY) for large buy orders and 13.8 BPS (I_BIG_SELL) for large sell orders. We isolate the costs of trading convertible bond positions on days when significant trading activity is on one side of the market by interacting I_BIG_BUY

[22]Our results are robust to an alternative definition of the effective spread, which is calculated as a simple average of the buy and sell prices. Appendix C of the Supplementary Material reports additional robustness tests related to our effective spread analysis.

TABLE 8

Effective Spread Regressions

Table 8 reports regressions of volume-weighted effective bid–ask spreads. The volume-weighted bid–ask spread is the dependent variable. Each regression includes a set of control variables and a set off additional dummy variables for estimating the incremental impact of trading different security types during different time periods. Robust standard errors are clustered by parent company CUSIP.

	Full Sample			Expected Volume Propensity-Matched Sample		
Variables	Coeff.	*t*-Stat.	*p*-Value	Coeff.	*t*-Stat.	*p*-Value
Panel A. Model 1						
I_CON	−0.114	−3.93	0.000	−0.037	−0.94	0.350
I_FALL_2008	0.077	17.04	0.000	0.055	5.77	0.000
I_FALL × I_CON	−0.012	−0.11	0.916	0.010	0.65	0.517
BOND_RATING	−0.004	−0.70	0.483	−0.014	−2.27	0.023
NO_BOND_RATING_INDICATOR	−0.010	0.15	0.882	−0.190	−2.33	0.020
YEARS_TO_MATURITY	0.011	12.39	0.000	0.017	8.07	0.000
TREASURY_TERM_SPREAD	3.078	14.62	0.000	3.556	11.15	0.000
STAND_DAILY_$_VOL	−0.012	−6.48	0.000	−0.030	−4.73	0.000
Constant	0.107	4.69	0.000	0.133	2.98	0.003
No. of obs.	1,428,301			77,647		
R^2	0.070			0.075		
No. of issuer CUSIPs	2,227			529		
Panel B. Model 2						
I_CON	−0.140	−4.80	0.000	−0.056	−1.27	0.203
I_FALL_2008	0.082	17.04	0.000	0.059	5.90	0.000
I_FALL × I_CON	−0.001	−0.11	0.916	0.020	1.33	0.184
BOND_RATING	−0.002	−0.70	0.483	−0.012	−1.93	0.053
NO_BOND_RATING_INDICATOR	0.006	0.15	0.882	−0.169	−2.00	0.046
YEARS_TO_MATURITY	0.011	12.39	0.000	0.017	8.22	0.000
TREASURY_TERM_SPREAD	3.081	14.62	0.000	3.545	11.37	0.000
STAND_DAILY_$_VOL	−0.011	−6.48	0.000	−0.024	−4.60	0.000
AGGREGATE_ORDER_IMBALANCE	−0.083	−8.07	0.000	−0.050	−2.57	0.010
I_BIG_BUY	0.081	13.43	0.000	0.081	6.92	0.000
I_BIG_SELL	0.138	37.72	0.000	0.147	13.11	0.000
I_BIG_BUY × I_CON	0.269	12.04	0.000	0.271	10.99	0.000
I_BIG_SELL × I_CON	−0.141	−14.39	0.000	−0.152	−10.43	0.000
Constant	0.107	4.69	0.000	0.089	1.92	0.055
No. of obs.	1,428,301			77,647		
R^2	0.093			0.099		
No. of issuer CUSIPs	2,227			529		
Panel C. Model 3						
I_CON	−0.139	−4.772	0.000	−0.056	−1.26	0.206
I_FALL_2008	0.082	17.04	0.000	0.059	5.90	0.000
I_FALL × I_CON	−0.012	−0.984	0.325	0.013	0.87	0.387
BOND_RATING	−0.002	−0.703	0.482	−0.012	−1.93	0.053
NO_BOND_RATING_INDICATOR	0.006	0.149	0.882	−0.169	−2.00	0.045
YEARS_TO_MATURITY	0.011	12.385	0.000	0.017	8.22	0.000
TREASURY_TERM_SPREAD	3.081	14.622	0.000	3.546	11.38	0.000
STAND_DAILY_$_VOL	−0.011	−6.482	0.000	−0.024	−4.60	0.000
AGGREGATE_ORDER_IMBALANCE	−0.083	−8.072	0.000	−0.050	−2.56	0.010
I_BIG_BUY	0.081	13.428	0.000	0.081	6.92	0.000
I_BIG_SELL	0.138	37.724	0.000	0.147	13.11	0.000
I_BIG_BUY × I_CON	0.263	11.808	0.000	0.265	10.83	0.000
I_BIG_SELL × I_CON	−0.140	−15.133	0.000	−0.150	−10.55	0.000
I_BIG_BUY × I_CON × I_FALL_2008	0.123	2.152	0.031	0.103	1.82	0.069
I_BIG_SELL × I_CON × I_FALL_2008	−0.017	−0.671	0.502	−0.025	−0.96	0.336
Constant	0.107	4.688	0.000	0.089	1.92	0.055
No. of obs.	1,428,301			77,647		
R^2	0.093			0.118		
No. of issuer CUSIPs	2,227			529		

and I_BIG_SELL with I_CON. We find that the effective spread for convertible bonds depends more on the direction of the trade than nonconvertible debt. Table 8 indicates that the effective spread widens to 35 BPS on BIG_BUY days (0.081 + 0.269) and narrows by only 0.3 BPS on BIG_SELL days (0.138–

0.141). Again, the results are relatively similar using the expected volume propensity-matched sample.[23]

Panel C of Table 8 examines the relative costs of trading convertible debt *during the fall of 2008* on days when order imbalances are high. The interaction between relatively large orders of convertible debt during the fall of 2008 allows us to partially isolate adverse selection costs from search costs. By controlling for the relative size of large buy and sell trades, one would expect that search costs would be approximately the same, all else equal. If anything, given that there already is a tendency in the fall of 2008 to have more seller-initiated trades, search costs for large sell orders would be expected to be higher, on average, than large buy orders. In this sense, our estimate represents a lower bound on the impact of adverse selection. The difference in the interaction terms indicates that the adverse selection component of the effective spread during the fall of 2008 for convertible debt was 10.6 BPS (0.123–0.017). The results for the propensity-matched subsample show a slightly lower estimate. For this subsample, the lower bound on adverse selection for convertible debt during the fall of 2008 is 7.8 BPS (0.103–0.025).

VIII. Trading Costs: The "True" Cost of Immediacy

HLLS argue that "when agents cannot trade or choose not to trade when costs are relatively high relative to their outside options, then trading volume diminishes, welfare declines, and the *cost of immediacy rises*." They argue that studies examining executed transactions ignore the opportunity costs of not trading and have the potential to provide a misleading picture of liquidity and market stability during periods of financial stress.

The HLLS "true" cost of immediacy (TCI) is calculated as the difference between the "true" value of the convertible bond (P) and the expected payoff from selling the bond immediately, that is,

$$\text{TCI} = P - (1 - \Pr(\text{FAIL})) \times E[B|\text{TRADE}] - \Pr(\text{FAIL}) \times R, \tag{10}$$

where $\Pr(\text{FAIL})$ is the probability of trade failure, $E[B|\text{TRADE}]$ is the expected best *bid* price conditional on a trade, and R is the seller's reservation price. Equation (10) can be arranged to accommodate estimation as follows:

$$\text{TCI} = E[P - B|\text{TRADE}] + \Pr(\text{FAIL})(E[B|\text{TRADE}] - R). \tag{11}$$

The first term is calculated as:

$$E[P - B|\text{TRADE}] = \text{PD} + 0.5 \times \text{EFF\_SPRD}, \tag{12}$$

where PD is the price discount from Section VI and EFF_SPRD is the effective spread from Section VII. Since PD is based on the midpoint, we add the effective half spread to adjust PD to the bid price.

[23]Grundy, Lim, and Verwijmeren (2012) show that spreads for options especially widen during the temporary 2008 short-sale ban. Appendix C of the Supplementary Material examines the convertible debt effective spread during this relatively short period.

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The second term in equation (11) is the expected cost of trade failure. The probability of trade failure (Pr(FAIL)) is abnormal trading volume. The bond's conversion value is the reservation price of R for convertible debt. Conversion value represents a lower bound for R because a convertible bond can contractually and at any time be converted into a predetermined number of shares of stock. Asness, Berger, and Palazzolo (2009) suggest this bound is tight. They argue that managers under pressure could only, in exceptional cases, not wait for the cash because the conversion process does not take more than a day or two before the shares are received and can be sold.

A. Estimation of the Probability of Trade Failure

The probability of trade failure is the abnormal trading volume for four different bond groupings: ITM convertibles, OTM convertibles, ITM propensity-matched nonconvertibles, and OTM propensity-matched nonconvertibles. It is estimated using two specifications: i) a weekly seasonal random walk (SRW) model and ii) a weekly first-order vector auto-regression (VAR) model. Table 9 reports the mean values for the fall of 2008 for different bond groupings. Columns 2 and 3 report results for the SRW and VAR models. Column 4 is the mean of columns 2 and 3. Panel A contains abnormal volume estimates for ITM and OTM convertible debt and the corresponding propensity-matched subsamples of nonconvertible debt; Panel B reports abnormal volume for convertible debt relative to propensity-matched nonconvertible debt.

As expected, Table 9 indicates that trading volume for convertible debt was abnormally low during the fall of 2008. Based on the SRW model, Panel A reports that the mean abnormal volume for ITM and OTM convertibles is 70.19% and 50.54% lower than the prior year. For the VAR model, the mean abnormal trading volume for ITM and OTM convertibles is −73.25% and−16.30% in the fall of 2008.

Panel B of Table 9 reports the incremental abnormal decline in trading volume for convertible debt relative to the propensity-matched subsamples of

TABLE 9

True Cost of Immediacy

Table 9 reports estimates of the true cost of immediacy using two different approaches to estimate the probability of a failed trade for different groupings of convertible and nonconvertible debt. All estimates are percentages.

	Abnormal Trading Volume						
Description	Seasonal Random Walk	Vector Auto-Regression	Median	Cost of Failed Trade	Effective Half Spread	Liquidity Discount	Cost of Immediacy
Panel A. Propensity-Based Volume Matches							
ITM convertible debt	−70.19	−73.25	−71.72	6.93	0.11	5.28	10.36
OTM convertible debt	−50.54	−16.30	−33.42	21.84	0.15	3.28	10.73
ITM propensity matches	−30.57	−17.92	−24.25	–	–	–	–
OTM propensity matches	19.80	11.95	15.87	–	–	–	–
Panel B. Abnormal Volume for Convertible Debt Relative to Propensity Matched Nonconvertible Debt							
ITM convertible debt	−39.62	−55.32	−47.47	6.93	0.11	5.28	8.68
OTM convertible debt	−70.34	−28.25	−49.29	21.84	0.15	3.28	14.20

nonconvertible debt. The SRW estimates are −39.62% for ITM convertible debt and −70.34% for OTM convertible debt. Based on the VAR model, the estimates are −55.32% for ITM convertible debt and −28.25% for OTM convertible debt.

Panels A and B of Table 9 indicate a significant increase in the risk of trade failure during the fall of 2008. These results are broadly consistent with the broad declines in market activity and support the predictions of Dugast et al. (2022).

B. Calculation of TCI

To calculate TCI, we also need to consider the cost of a failed trade. As discussed above, the lower bound for the cost of a failed trade is conversion value. Column 5 in Table 9 reports the mean of the cost of a failed trade over the fall of 2008 for ITM and OTM convertible debt. For each convertible bond, the cost of a failed trade is its daily conversion value (the difference between the price of the underlying stock minus the conversion price, multiplied by the number of shares received upon conversion) scaled by the corresponding model price. We find that the cost of a failed trade is 6.93% and 21.84% for ITM and OTM convertible bonds.

Based on the estimates in Table 9, the true cost of immediacy (see equation (10)) is 10.36% for ITM convertible debt and 10.73% for OTM convertible debt. If we make the analogous calculation using abnormal convertible debt volume relative to the propensity-matched nonconvertible debt, the cost of immediacy for ITM and OTM convertible debt is 8.68% and 14.20%, respectively.

We note that our TCI estimates are comparable and consistent with the MP estimates based on quotations. This correspondence indicates that convertible debt holders that needed immediate liquidity during the fall of 2008 would have liquidated at very high discounts.

IX. Dealer Markup Results Using RPTs

A customer and dealer's decision to pre-arrange a trade versus holding it in inventory is endogenous to a bond's liquidity. For that reason, simply looking at realized markups from trading during crisis periods would be subject to a selection bias – a crisis may also affect a dealer's expectation of future inventory costs or the effort required to find a counterparty to pre-arrange a trade.

We follow Goldstein and Hotchkiss (2020) and use a 2-stage endogenous switching model to control for this endogenous effect on realized markups. In the first stage, we estimate a probit model that regresses the type of trade (a dummy variable indicating whether the roundtrip trade was pre-arranged or executed in 15 minutes or less) on dummy variables specific to our dif-in-dif design, s set of control variables X_{jt}, and an instrumental variable, EQUITY_TRADES.

$$\text{(13)} \quad \begin{aligned} \text{TRADE\_TYPE}_{jt} = {} & \alpha + \beta^{\text{FALL}}\text{I\_F\_2008}_t + \beta^{\text{CON}}\text{I\_CON}_t \\ & + \beta^{\text{FALL\_CON}}\text{I\_F\_2008}_t \times \text{I\_CON}_j + \theta X_{jt} \\ & + \omega \text{EQUITY\_TRADES}_{t-1} + \varepsilon_{jt}, \end{aligned}$$

where X_{jt} is a vector that includes I_BIG_TRADE (a dummy variable that indicates whether the roundtrip trade was in the top 10% of trades that day),

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the lagged volume-weighted effective spread, and the number of transactions the dealer undertakes between opening and closing an estimated position (ROUNDTRIP_LENGTH).

We include a big trade dummy because this type of trade is more likely to require additional effort to locate a counterparty and is, therefore more likely to be executed as a RPT. Roundtrip length is a measure of the effort required by the broker/dealer to find offsetting counterparties. The relation between roundtrip length, the likelihood of a principal trade, and the associated markup is unclear. On the one hand, inventory transactions may take longer to complete because they require the broker/dealer to find multiple counterparties. On the other hand, bond sellers may choose a RPT when they realize that finding a counterparty will be challenging and broker/dealer search costs will be high.

We strengthen our identification by augmenting the selection model with an instrument based on the lagged number of trades in the *equity* market (EQUITY_TRADES). For EQUITY_TRADES to be a valid instrument, we expect it to correlate with characteristics of the trading environment for *fixed-income* securities. However, we do not expect it to be an explicit determinant of bond markups. In effect, the model as a whole is identifiable because the instrument, which is included in the first-stage estimation, is excluded in the second-stage specification.

To satisfy the exclusion restriction, EQUITY_TRADES needs to be uncorrelated with the true error of the second-stage regression for proper identification. Since EQUITY_TRADES enters the information set on day $t-1$ and reflects trading activity in a different market, we would not expect it to affect dealer markups directly.[24]

The second stage then includes the predicted value for the trade type from the first stage, along with the same set of control variables:

$$\text{(14)} \quad \text{REALIZED\_MARKUP}_{jt,\text{type}} = \alpha + \beta^{\text{FALL}}\text{I\_F\_2008}_t + \beta^{\text{CON}}\text{I\_CON}_t + \beta^{\text{FALL\_CON}}\text{I\_F\_2008}_t \times \text{I\_CON}_j + \theta X_{jt} + \varepsilon_{jt}.$$

Our results are presented in Table 10. Model 1 reports the first-stage probit model results, whereas models 2 and 3 present the results of the second-stage markup regressions.

The trade type model indicates that, as a general rule, convertible bonds are more likely to be held in inventory ($\beta^{\text{CON}} > 0$) than nonconvertible debt. Consistent with Hypothesis 5, this changes during the fall of 2008 where we find that all bond trades, convertible and nonconvertible, became more likely to be pre-arranged ($\beta^{\text{FALL}} = -0.033$, z-stat. = -8.830 and $\beta^{\text{FALL\_CON}} = -0.013$, z-stat. = -0.62).

Investors that choose to sell convertible debt in the fall of 2008 as RPTs can expect to trade at markups that are 59 BPS higher compared to more liquid periods.

[24]Formally, two conditions must be satisfied for a valid instrument in a two-stage least squares regression: i) the relevance condition and ii) the exclusion restriction. To meet the relevance condition, the instrument in the first stage regression must be sufficiently correlated with the choice of trade type. Table 10 indicates this is the case (z-stat. = -97.480). As discussed above, the exclusion restriction requires the instrument to be uncorrelated with the true error of the endogenous data-generating process – the choice of trade type. As is standard, this is handled via an intuitive discussion of why this is expected to be the case.

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TABLE 10

Realized Markups on Dealer Roundtrip Trades with Endogenous Inventory Decision

Table 10 reports endogenous switching regression results of realized dealer markups. The columns under the heading Trade Type report the first-stage results from a probit model on the decision whether to pre-arrange a trade versus hold it in inventory. We consider the trade to be pre-arranged (TRADE_TYPE = 0) if a dealer trades a bond and then a dealer creates an offsetting position in the same bond within 15 minutes (at least one of those trades must also involve a customer). If the trade takes longer than 15 minutes to offset, we consider the trade to have entered the dealer's inventory, and call that TRADE_TYPE = 1 in our first-stage estimation. The columns under the heading Pre-Arranged Markup and Inventory Markup report the second-stage estimation results testing the effect of the fall of 2008 on dealers' realized markups from roundtrip trading on these bonds, conditional on the predicted value of $\widehat{\text{TRADE\_TYPE}}$ from the first stage.

	Trade Type		Prearranged Markup		Inventory Markup	
	Coeff.	*z*-Stat.	Coeff.	*z*-Stat.	Coeff.	*z*-Stat.
Variables	1		2		3	
EQUITY_TRADES	−0.131	−97.480				
I_F_2008	−0.033	−8.830	−0.094	−56.290	0.309	29.910
I_CON	0.590	85.310	0.002	0.280	0.045	2.600
I_F_2008 × I_CON	−0.013	−0.620	0.151	11.610	0.001	0.010
I_BIG_TRADE	0.075	26.470	−0.011	−7.640	0.069	9.130
LAGGED_EFFECTIVE_SPREAD	15.295	32.860	61.888	263.640	195.055	168.420
ROUNDTRIP_LENGTH	0.244	186.930	0.050	24.190	0.024	10.640
INVERSE_MILLS_RATIO			0.414	28.810	0.388	20.850
Constant			0.561	231.970	0.075	2.090
No. of obs.	2,300,489					

By contrast, dealers charge markups that are 94 BPS *lower* for investor selling nonconvertible debt.[25] The incrementally higher cost of trading convertible debt is likely attributable to higher search costs as dealers search for counterparties when illiquidity is abnormally high in the convertible debt market in the fall of 2008.

Dealers charge systematically higher markups if they take bonds into inventory. For inventory trades, investors pay markups that are 355 BPS higher all else equal. Investors selling nonconvertible debt pay smaller but still economically large markups of 309 BPS when dealers take nonconvertible bonds into inventory.[26] These results indicate that dealers charge significantly more if they are asked to bear the price risk from holding bonds as they search for traders willing to take the transaction's other side.

The incremental cost savings associated with RPTs relative to inventory trades respectively are 296 (533–59) BPS and 403 (309 + 94) BPS. This difference likely reflects the reduction in adverse selection when dealers understand the trading motivations of convertible bond hedge funds. Trader motivations are less clear when dealers are asked to trade nonconvertible debt and charge a relatively higher markup. Taken as a whole, these findings are consistent with Hypothesis 6 and suggest that the ability to search and identify counterparties is especially valuable for these bonds during the fall of 2008.[27]

[25]The incremental markup for investors selling convertible debt as a riskless principal trade in the fall of 2008 is calculated as $\beta^{\text{FALL}} + \beta\text{CON} + \beta^{\text{FALL\_CON}} = -0.094 + 0.002 + 0.015 = 0.059$, or 59 bps. The analogous calculation for nonconvertible debt is $\beta^{\text{FALL}} = -.094$, or − 94 bps.

[26]The incremental markup for investors selling convertible debt as an inventory trade in the fall of 2008 is calculated as $\beta^{\text{FALL}} + \beta\text{CON} + \beta^{\text{FALL\_CON}} = 0.309 + 0.045 + 0.001 = 0.355$, or 355 bps. The analogous calculation for nonconvertible debt is $\beta^{\text{FALL}} = 0.309$, or 309 bps

[27]Appendix E of the Supplementary Material contains an additional robustness check that includes incremental effects for financial firms subject to the 2008 short sale ban. We find that financial issuers'

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X. Conclusion

When Lehman Brothers declared bankruptcy on Sept. 15, 2008, fixed-income markets were under significant stress. Investment banks' access to rehypothecation lending was significantly limited, causing banks to curtail lending to their prime brokerage hedge fund clients. Ultimately, these hedge funds liquidated convertible positions when illiquidity in fixed-income markets was historically high.

Existing literature has suggested that "slow-moving capital" could not arbitrage these securities effectively during the fall of 2008, and liquidating funds would have been required to sell their positions at substantial discounts (as much as 13%) if they demanded immediate liquidity. We provide confirmatory evidence showing that the expected cost of obtaining immediate liquidity exceeded 10% over this period. These estimates recognize that when markets become illiquid, the number of sellers who chose not to trade or could not locate a willing buyer is unobservable.

Suppose investors have the patience and resources to engage in, for instance, riskless principal trading, the sale of alternative assets, or liquidating cash holdings. In these cases, they can mitigate the impact of the liquidity shock caused by the crisis. For example, Asness, Berger, and Palazzolo (2009) recount that "[o]ne counterweight to this cycle was the term financing arrangements used by some arbitrageurs and prime brokers. In these arrangements, prime brokers could not simply call back their financing (or change their terms) overnight. Typically, before these terms could change, either the prime broker had to give arbitrageurs advance notice (often 30–90 days) or the borrower or prime broker had to trip certain triggers. This arrangement gave some arbitrageurs time and flexibility, so in practice, all levered investors in convertible bonds did not have to sell in the exact same day or week."

By arranging RPTs, dealers could connect investors to sellers and bring new capital to the market. The share of RPTs increased, and dealers charged wider spreads for searching to arrange these trades during the fall of 2008. Consistent with the greater reliance on riskless principal trading to avoid immediate liquidation, our analysis of transaction prices indicates that during this period, realized price discounts only averaged 2%.

For those trades that did occur, and unlike trading in equity markets where trades are anonymous, dealers execute trades in voice markets where the identities of counterparties are known. Since dealers can infer that an exogenous shock caused hedge fund liquidations, the adverse selection component is ameliorated. Lower adverse selection costs resulted in substantially smaller discounts and bid–ask spreads. Additionally, these hedge funds could still finance their positions while

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bonds are more likely to be pre-arranged, especially during the fall of 2008. We also show that sales of pre-arranged trades of financial issuer bonds are charged a lower realized markup and that the markup is reduced even more during the fall of 2008. Appendix F of the Supplementary Material examines the trading behavior of large institutional investors by analyzing position data reported in 13-F filings. Prior to the fall of 2008, the institutional market for convertible debt was largely self-contained (i.e., purchases and sales of convertible debt largely offset each other). Consistent with the evidence discussed above, this pattern changed during 2008Q3 and 2009Q1 where net sales of $2,269 million exceeded net purchases of $1,821 million.

dealers worked on arranging "riskless principal" trades with counterparties rather than having to sell immediately at steep discounts.

Recent regulatory and academic studies such as the U.S. Treasury Office of Financial Research's "Asset Management and Financial Stability" report and Goldstein, Jiang, and Ng (2017) consider the possibility that portfolio liquidations by bond funds responding to investor redemptions in a crisis period can contribute to financial fragility or fire-sale risk. Our evidence suggests that bond liquidity can be surprisingly resilient to redemption risk under the current dealer-intermediated market structure, perhaps because dealers know their customers and can connect them through riskless principal trading when intermediary capital is scarce. There is ample evidence from the recent literature on the Covid-19 pandemic, however, that supports the notion that liquidity crises are a recurrent phenomenon and lead to substantial market distortions (e.g., O'Hara and Zhou (2021)). The convertible bond crisis may thus have been special in this regard, allowing hedge funds to be more patient than, say, bond mutual funds during Covid-19, in liquidating their positions.

Appendix. Variable Definitions

AGGREGATE_ORDER_IMBALANCE ($\text{AGG\_ORDER\_IMBAL}_{jt}$): AGG_ORDER_IMBAL_t is calculated as the daily mean of ORDER_IMBAL_{jt} across all bonds.

AGGREGATE_VOLUME (AGG_VOL_{jt}): Aggregate volume for bond j on day t (AGG_VOL_{jt}) is calculated as the sum of the dollar volume of dealer buy orders ($\$\text{BUY\_VOL}_{jt}$) plus the dollar volume of dealer sell orders ($\$\text{SELL\_VOL}_{jt}$). In the regression specifications, we transform AGG_VOL_{jt} into a "z-score" (Z_AGG_VOL_{jt}) by subtracting the mean and scaling by its standard deviation.

BIG_BUY (I_BIG_BUY_j): An indicator variable that takes the value 1 if the order imbalance for bond j on day t is negative and in the top 10-percentile of the daily order imbalance distribution across all securities.

BIG_SELL (I_BIG_SELL_j): An indicator variable that takes the value 1 if the order imbalance for bond j on day t is positive and in the top 10-percentile of the daily order imbalance distribution across all securities.

BIG_TRADE (I_BIG_TRADE): Indicates whether the roundtrip trade was in the top 10% of trades that day.

CONVERTIBLE_BOND_INDICATOR (I_CON_j): An indicator variable that takes the value 1 if security j is a convertible bond, and 0 otherwise.

EFFECTIVE_SPREAD (EFF_SPRD_{jt}): Following Hong and Warga (2000) and Chakravarty and Sakar (2003), we construct a daily measure that exploits the buy/sell indicator in the Enhanced TRACE data set. Since broker sells are reported at the ask and broker buys at the bid, the effective spread for bond j on day t is calculated as the difference between the daily volume-weighted ask price (A_{jt}^{VOL}) and bid price (B_{jt}^{VOL}) scaled by the corresponding bid–ask midpoint.

$$\text{EFF\_SPRD}_{jt} = \frac{A_{jt}^{\text{VOL}} - B_{jt}^{\text{VOL}}}{\left(A_{jt}^{\text{VOL}} + B_{jt}^{\text{VOL}}\right)/2}, \quad \text{(A-1)}$$

where

$$A_{jt}^{\text{VOL}} = \sum_{k=1}^{K} \text{VOL}_{kjt}^{A} P_{kjt}^{A} \Big/ \sum_{k=1}^{K} \text{VOL}_{kjt}^{A}$$

$$B_{jt}^{\text{VOL}} = \sum_{k=1}^{K} \text{VOL}_{kjt}^{B} P_{kjt}^{B} \Big/ \sum_{k=1}^{K} \text{VOL}_{kjt}^{B},$$

VOL_{kjt}^{A} is the size of dealer sale trade k for bond j on day t, VOL_{kjt}^{B} is the size of dealer buy trade k for bond j on day t, P_{kjt}^{A} is the price of bond j on day t for dealer sale trade k, and P_{kjt}^{B} is the price of bond j on day t for dealer buy trade k.

There is no guarantee that our effective spread measure is strictly positive. For example, suppose a dealer sold 1,000 bonds at an ask price of \$99.90, $A_{jt}^{\text{VOL}} = \$9{,}990.00$ and that after the trade was executed the bond price increased and the resulting bid and ask prices respectively increased to \$100.25 and \$100.49. If the dealer then bought 1,000 bonds to flatten its books $A_{jt}^{\text{VOL}} = \$10{,}049.00$, the effective spread is -0.0029 (i.e., $(9{,}990 - 10{,}049)/(9{,}990 + 10{,}049)$. To control for this possibility, we use an effective spread measure that has been winsorized at the 5% level.[28]

FALL_OF_2008 (I_F_2008_j): I_F_2008_j is an indicator variable that takes the value 1 if the trading date falls within the window beginning on Sept. 1, 2008 and ending on Nov. 30, 2008, and 0 otherwise.

PRICE_DISCOUNT (PD_{jt}): The price discount (or premium) is estimated as:

$$\text{PD}_{jt} = \frac{\text{MODEL}_{jt} - P_{jt}}{\text{MODEL}_{jt}}, \quad \text{(A-2)}$$

where $P_{jt} = \left(A_{jt}^{\text{VOL}} + B_{jt}^{\text{VOL}}\right)/2$ and MODEL_{jt} is calculated using the Tsiveriotis-Fernandes (1998) model using the Fixed Income Toolbox in Matlab. We employ a standard trinomial tree with 501 time steps. Stock prices and returns (for calculating volatility) are obtained from CRSP. We calculate volatility as the standard deviation of the stock price using the past 90-days that precede the valuation date t. Annualized continuously compounded dividend yields are estimated from CRSP by assuming that the past four quarters dividend payments approximate the expected annual dividend yield over the life of the bond. The term structure of the risk-free rate is estimated from the yield to maturities of U.S. Treasury bonds at 1, 3, 5, 7, 10, 20, and 30 year horizons. The data is obtained from the Federal Reserve Board's FRED website. Credit spreads are estimated across all rating categories as the average deviation between the yield to maturity for a specific rating category at date $t-1$ and the yield on a 10-year U.S. Treasury bond. This has the advantage of changing over time to reflect current market conditions. The bond ratings are obtained from Mergent, the yields from the Enhanced Trace data, and the Treasury rates from The Federal Reserve Board's FRED website.

[28]Our results are qualitatively similar if we use either unadjusted effective spreads or effective spreads that have been winsorized at the 1% level.

Bond-specific contractual features are obtained from Mergent. These include the coupon rate, face value, time to maturity, conversion price, and call schedule (call prices and call dates).[29]

PRICE_DISCOUNT_FIXED_EFFECTS (PD^e_{jt}): The residual from a panel regression model that removes bond-specific fixed effects PD_{jt}. This controls for systematic biases in bonds over the entire sample period.

ORDER_IMBALANCE ($ORDER\_IMBAL_{jt}$): Following Chordia, Roll, and Subrahmanyam (2001), we estimate order imbalance for bond j on day t as the difference between $\$BUY_VOL_{jt}$and $\$SELL\_VOL_{jt}$ scaled by the sum of the dollar volume of dealer buy and sell orders, that is,

$$ORDER\_IMBAL_{jt} = \frac{\$BUY\_VOL_{jt} - \$SELL\_VOL_{jt}}{\$BUY\_VOL_{jt} + \$SELL\_VOL_{jt}}.$$

A positive value indicates that investors were net sellers and dealers net buyers.

TRUE_COST_OF_IMMEDIACY (TCI): The HLLS true cost of immediacy. Calculation details are provided in Section VIII.

ZERO_DAYS ($ZERO\_DAYS_{jt}$): Calculated as the number of days that elapse between days where there was at least one buy and one sell order.

Supplementary Material

To view supplementary material for this article, please visit http://doi.org/10.1017/S0022109023000583.

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