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POVZETEK: Raziskava obravnava heterogeno slabost likvidnosti, pretraževalne omejitve in elektronsko izvrševanje v trgu lokalnih zaveznih bonov. Izpeljana je, da slabost likvidnosti ne prikazuje se enako v različnih stresnih okoliščinah. V razdoblju finančnega kriza 2007-2009 se slabost likvidnosti izraža premorenimi troški, medtem ko v razdoblju pandemije COVID se slabost prikazuje v manjši tržni aktivnosti in parnem obnemoru. Raziskava tudi povezuje med poškodbo likvidnosti in elektronskim izvrševanjem skozi alternativne tržne sisteme (ATS), zaznamov je, da elektronsko izvrševanje ni vedno povezano z manjšimi pretraževalnimi omejitvami in troški.

METODA: Raziskava uporablja podatke o 215.773.158 transakcijah lokalnih zaveznih bonov v obdobju od 2005 do 2025, ki pokrivajo 71.17 trilijonov dolara v parnem obnemoru. Prva delovnica raziskave obravnava slabost likvidnosti v različnih stresnih okoliščinah, kot so finančni krizni obdobje in pandemija COVID. Druga delovnica povezuje dolgo obdobje slabosti likvidnosti z razvojem elektronskega izvrševanja skozi alternativne tržne sisteme (ATS).

KLJUČNE UGOTOVITVE:

- Slabost likvidnosti v lokalnem zaveznem trgu ne prikazuje se enako v različnih stresnih okoliščinah.
- V razdoblju finančnega kriza 2007-2009 se slabost likvidnosti izraža premorenimi troški, medtem ko v razdoblju pandemije COVID se slabost prikazuje v manjši tržni aktivnosti in parnem obnemoru.
- Elektronsko izvrševanje skozi ATS ni vedno povezano z manjšimi pretraževalnimi omejitvami in troški.

POMEN ZA TRGOVANJE: Raziskava je uporabna za trgovce, saj pokaže, da elektronsko izvrševanje ni vedno povezano z manjšimi troški in pretraževalnimi omejitvami. Trgovci morajo razumeti, da slabost likvidnosti v lokalnem zaveznem trgu se prikazuje različno v različnih stresnih okoliščinah, kar pomeni, da morajo sprejemati različne strategije za manjšanje pretraževalnih omejitv in troškov.

Heterogeneous Liquidity Fragility, Search Frictions, and Electronic Execution in the Municipal Bond Market

Pengjie Zhou¹, Yucheng Wu²

Abstract: Municipal bonds are central to U.S. public finance, yet their secondary market is fragmented, dealer-intermediated, and vulnerable to liquidity stress. Using 215,773,158 MSRB transaction records from 2005 to 2025, covering \$71.17 trillion in reported par volume, we study how liquidity fragility appears in the U.S. municipal bond market across different stress episodes.

We find that fragility does not take a single form. During the 2007-2009 financial crisis, it appears mainly through transaction costs. The median positive paired-trade spread rises by 69.2 percent, the winsorized mean positive spread rises by 25.0 percent, and market-wide par volume falls by 52.9 percent. However, during COVID, the pattern is different. From 2019 to 2021, market-wide trade count falls by 12.1 percent, par volume falls by 22.8 percent, and the paired sample contracts by 12.8 percent, even though positive-spread medians decline. This suggests that COVID-period fragility is more visible in trading activity, par volume, and sample composition than in the price margin alone.

We then examine the post-2022 expansion of electronic execution through Alternative Trading Systems (ATS) and test whether electronic execution is associated with lower search frictions and transaction costs. In the 2018-2025 customer-dealer ATS sample, 14,950,299 of 27,199,280 pairs, or 55.0 percent, have dealer-side ATS participation. ATS appears on the dealer leg rather than the customer leg, and its association with spreads depends on trade direction. P-D, D-P, and S-D pairs have lower positive-only spreads with dealer-side ATS, while D-S pairs move in the opposite direction. The evidence supports a market-design interpretation based on heterogeneous liquidity fragility and dealer-side search frictions, rather than a broad claim that electronic trading uniformly lowers transaction costs.

Keywords: Municipal bonds; liquidity fragility; transaction costs; search frictions; dealer intermediation; alternative trading systems; electronic execution; OTC markets; VIX; MOVE.
JEL classification: G12; G14; G20; G23; H74.

1. Introduction

The municipal bond market, as an important segment of the U.S. financial market, is vulnerable to liquidity fragility. Municipal bonds finance schools, utilities, hospitals, transportation systems, and state and local governments. Yet their secondary market is fragmented, dealer-intermediated, and much less centralized than equity or Treasury markets. Many municipal bonds trade only sporadically, and customer trades usually pass through dealers rather than a continuous public limit order book. These features make liquidity depend heavily on search, dealer balance sheets, and the willingness of intermediaries to provide immediacy.

Liquidity fragility in this market may not appear on a single margin. Under stress, transaction costs may rise, but trading activity may also fall, par volume may contract, fewer bonds may trade, or the composition of observable trades may change. A market can therefore look active

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by trade count while becoming fragile by par volume or transaction cost. Conversely, positive-spread medians may decline if the trades that remain in the paired sample are easier to match. For this reason, municipal bond liquidity fragility should be measured through both price and non-price margins.

This paper studies these issues using MSRB municipal bond transaction records from 2005 to 2025. The market-wide sample contains 215,773,158 reported trades, \$71.17 trillion in reported par volume, and 3,411,210 distinct CUSIPs that appear at least once during the sample period. In a typical year, about 514,653 unique CUSIPs trade. We also construct a customer-dealer paired-trade sample with 52,595,988 pairs matched by CUSIP, trade date, and par amount. This paired sample allows us to measure implied transaction costs when posted bid and ask quotes are not continuously available.

The first part of the paper examines liquidity fragility across macro stress episodes. The global financial crisis and COVID provide a useful contrast. During the 2007-2009 financial crisis, fragility appears mainly through transaction costs: positive customer-dealer paired spreads rise sharply while par volume contracts. During COVID, however, the median positive paired-trade spread does not widen. Instead, fragility appears in lower market-wide activity, lower par volume, a smaller paired transaction-cost sample, more same-time matching, and a larger zero-spread mass. This comparison shows that municipal bond liquidity fragility should not be defined only as an increase in median positive spreads.

The second part of the paper connects this long-run fragility evidence to the post-2022 expansion of Alternative Trading Systems (ATS). If part of municipal bond illiquidity comes from search and dealer intermediation, electronic execution should not have the same association with every type of trade. The data support this view. In the 2018-2025 customer-dealer ATS sample, ATS participation appears on the dealer leg rather than the customer leg, and its association with spreads differs across P-D, D-P, S-D, and D-S pairs. This makes a simple ATS indicator too coarse. We therefore study dealer-side ATS participation interacted with trade direction.

The major contributions of this study are threefold. First, we provide a long-run set of market-wide and paired-trade facts for municipal bonds. The analysis combines market-wide activity measures with paired transaction-cost measures and covers multiple market environments, including expansion, crisis, recovery, COVID, and the post-2022 electronic trading period. Second, we show that municipal bond liquidity fragility is heterogeneous. The financial crisis is mainly a transaction-cost episode, while COVID is more visible in activity, par volume, paired-sample composition, time gaps, and zero-spread mass. Third, we study the post-2022 ATS expansion as a dealer-side search-friction channel rather than as a simple electronic-trading effect. This distinction matters because ATS participation is concentrated on the dealer leg and its association with spreads depends on trade direction.

The paper proceeds as follows. Section 2 reviews the literature on liquidity fragility, OTC bond transaction costs, municipal bond search frictions, and electronic execution. Section 3 describes the MSRB data, paired-trade construction, and empirical design. Section 4 presents the long-run evidence on heterogeneous liquidity fragility across macro stress episodes. Section 5 examines dealer-side ATS participation and direction-specific search frictions. Section 6 discusses the interpretation, policy implications, limitations, and conclusion.

2. Literature Review

This paper relates to four strands of literature.

The first strand studies liquidity fragility in financial markets. A central lesson from this literature is that liquidity is state-dependent. It can deteriorate when volatility rises, funding conditions tighten, or intermediaries reduce balance-sheet capacity. Brunnermeier and Pedersen (2009) provide the classic framework linking market liquidity and funding liquidity. In equity markets, Hameed, Kang, and Viswanathan (2010) show that stock market liquidity worsens during market declines. In Treasury markets, Longstaff (2004) documents a flight-to-liquidity premium in Treasury bond prices, while Duffie (2020) and Vissing-Jorgensen (2021) show that even the Treasury market became fragile during the March 2020 “dash for cash.” These studies motivate our view that liquidity fragility should not be measured only by whether trades occur. Under stress, trading may continue, but the cost, size, breadth, and composition of trading may change.

The second strand studies transaction costs in OTC bond markets. There are numerous studies on transaction costs and dealer behavior in the corporate bond market. Schultz (2001) studies corporate bond trading costs before full post-trade transparency. Bessembinder, Maxwell, and Venkataraman (2006) and Bessembinder and Maxwell (2008) show that TRACE increased transparency and reduced corporate bond transaction costs. Goldstein, Hotchkiss, and Sirri (2007) show that broader price information can improve investors’ ability to negotiate. Edwards, Harris, and Piwowar (2007) estimate corporate bond trading costs using transaction data. Goldstein and Hotchkiss (2020) further show that dealers in illiquid corporate bonds often offset trades within the same day rather than hold risky inventory for long periods. These papers are relevant because municipal bonds are also traded in an OTC market with limited pre-trade transparency and important dealer intermediation.

Municipal bonds, however, warrant separate investigation. The municipal bond market is significantly different from the corporate bond market. Tax treatment, credit structure, call features, retail ownership, local clientele, and issue fragmentation all affect trading. Hong and Warga (2004) provide early evidence that retail-sized municipal bond trades have much higher spreads than institutional trades. They also suggest that volatility, maturity, trade volume, coupon, callability, and pre-refunded status are important determinants of bid-ask spreads. Harris and Piwowar (2006) remain a benchmark study of secondary-market transaction costs in municipal bonds. They estimate trading costs for more than 167,000 municipal bonds and show that costs decrease with trade size but increase with maturity and time since issuance. Green, Hollifield, and Schurhoff (2007) emphasize financial intermediation and the costs of trading in an opaque municipal bond market.

A closely related group of papers studies search frictions, clientele, and dealer networks. As key players in the OTC market, brokers and dealers represent two major forms of financial intermediation. Brokers serve as agent dealers for customers who need market access and counterparty search services. Market makers serve as principal dealers by buying and selling bonds from inventory when customers demand immediacy. Dealers who serve as agents have spreads that vary with search and negotiation costs, while dealers who make markets require compensation for inventory risk and adverse-information risk. Butler (2008), Butler, Fauver, and Mortal (2009), and Pirinsky and Wang (2011) provide evidence of local and clientele effects in municipal finance. Hollifield, Neklyudov, and Spatt (2017) show that dealer network structure affects spreads. Schwert (2017) decomposes municipal bond spreads into default and liquidity components. More recently, Brancaccio and Kang (2025) show that municipal bond search frictions can be shaped by product design: non-standard provisions can increase search costs and advantage originating underwriters in the secondary OTC market.

Recent work on COVID and investor demand is especially important for this paper. Choi and Shim (2023) study mutual fund fragility, dealer liquidity provision, and the COVID-19 crisis in the municipal bond market. Their work is closely related to our COVID evidence because it links redemption pressure and dealer capacity to municipal bond liquidity. Recent Brookings work on investor demand and municipal bond liquidity also emphasizes that shocks to investor types can reshape trading composition. These studies help explain why COVID-period fragility may appear through market activity, par volume, paired-sample composition, and zero-spread mass rather than through wider median positive spreads alone.

The final strand concerns electronic execution and market design. In a search-based OTC market, electronic trading can affect liquidity through several channels. It may reduce search costs, improve routing, or help dealers manage inventory. But it may also operate mainly through the dealer or interdealer side of the market rather than directly lowering customer transaction costs. Recent MSRB evidence on municipal bond ETFs and market liquidity suggests that electronic channels have become more important in municipal securities trading. The U.S. Treasury (2024) discussion of ATS structure also highlights that electronic venues can reshape dealer and interdealer market structure. This literature motivates our treatment of ATS as a dealer-side execution channel rather than a simple market-wide electronic trading indicator. Overall, the existing literature provides the foundation for our empirical design. Prior work shows that municipal bond trading costs are large, search frictions matter, and dealer intermediation is central to price formation. Recent work further suggests that liquidity fragility can operate through investor demand, dealer balance sheets, and electronic trading structure. Our contribution is to combine these ideas in a long-run municipal bond setting: we study liquidity fragility across macro stress episodes and then examine whether post-2022 dealer-side ATS participation is associated with direction-specific differences in paired-trade spreads.

3. Data and Methods

We obtain municipal bond transaction data from the Municipal Securities Rulemaking Board (MSRB) through EMMA. The cleaned market-wide sample covers trade reports from 2005 to 2025 and contains 215,773,158 transactions, representing \$71.17 trillion in reported par volume. The data include CUSIP, trade date, settlement date, trade type, par amount, transaction price, coupon, maturity date, and other bond and transaction characteristics.

The market-wide sample is used to measure the extensive margin of liquidity. These measures include annual trade count, total par volume, unique traded CUSIPs, and average trades per CUSIP. Across the 2005-2025 sample, 3,411,210 distinct CUSIPs appear at least once. In a typical year, about 514,653 unique CUSIPs trade, and the maximum annual number of unique traded CUSIPs is 597,950. The full transaction sample contains 50,356,087 dealer purchases from customers, 89,993,085 dealer sales to customers, and 75,423,986 interdealer trades.

MSRB trade type indicators are defined from the dealer's perspective. A trade is coded as P when a dealer purchases a bond from a customer, S when a dealer sells a bond to a customer, and D when the trade occurs between dealers. This distinction is important because customer-dealer trades and interdealer trades capture different parts of the trading process. Customer trades reflect the cost of immediacy and market access faced by end investors, while interdealer trades reflect how dealers manage inventory and search for offsetting counterparties.

To measure transaction costs, we construct a customer-dealer paired-trade sample. Municipal bonds do not have continuously posted bid and ask quotes for each security, so quoted spreads

are not directly observed. We therefore infer transaction costs from matched trades. Within each CUSIP-date-par amount cell, we form ordered pairs of customer-dealer related trades:

$$M_{c,d,v} = \{(i,j): CUSIP_i = CUSIP_j = c, Date_i = Date_j = d, Par_i = Par_j = v, i < j\}.$$

For each pair, we define the transaction-cost spread, zero-spread indicator, and time gap as:

$$TC_{ij} = |Price_i - Price_j|, \quad Z_{ij} = 1\{TC_{ij} = 0\}, \quad Gap_{ij} = |Time_i - Time_j|.$$

The paired sample contains 52,595,988 customer-dealer pairs from 2005 to 2025. Of these, 38,813,488 pairs have positive spreads and 13,782,500 pairs have zero spreads. Zero-spread pairs are not dropped from the data. They account for 26.2 percent of the paired sample and are informative about matching, reporting, electronic execution, and market structure. In the full paired sample, 53.3 percent of pairs have a zero-second time gap, but only 16.9 percent have both zero time gap and zero spread. Same-time matching and zero-spread matching are therefore related, but they are not the same object.

The paired-trade sample is small-trade intensive, which is consistent with the retail structure of the municipal bond market. The median par amount is \$25,000, while the mean par amount is about \$96,613. The median maturity is 10.219 years, and the median coupon is 5.000 percent. The median absolute paired-trade spread is 0.163 price points. Among positive-spread pairs, the median spread is 0.450 price points. The median time gap between matched legs is zero seconds, while the mean time gap is 623 seconds.

The main control vector is:

$$X_{p,t} = [\log(Par_{p,t}), Maturity_{p,t}, Coupon_{p,t}, BondAge_{p,t}, AvgPrice_{p,t}, \log(1 + Gap_{p,t}), VIX_t, MOVE_t].$$

The controls capture trade size, bond characteristics, matching speed, and market-level volatility. VIX captures equity-market volatility and broad risk aversion, while MOVE captures Treasury-rate volatility and fixed-income market stress. In specifications with trade-date fixed effects, date-level variables such as VIX and MOVE are absorbed by the fixed effects and are not separately estimated.

For the first part of the paper, we combine market-wide extensive-margin measures with paired-trade transaction-cost measures. The baseline stress specification can be written as:

$$Cost_{p,t} = \alpha + \beta Stress_t + \theta' X_{p,t} + \gamma_{CUSIP(p)} + \delta_t + \varepsilon_{p,t}.$$

Here, $Cost_{p,t}$ is a paired-trade spread measure. $Stress_t$ can be an event-period indicator, VIX, MOVE, or interactions between stress episodes and volatility. The preferred specifications include CUSIP fixed effects and trade-date fixed effects where feasible. These fixed effects compare trades within the same bond and absorb common daily market conditions.

For the second part of the paper, we use the ATS-related fields available in the 2018-2025 data. The ATS sample is restricted to customer-dealer pairs with directions P-D, D-P, S-D, and D-S. Pure D-D pairs are excluded from the main customer transaction-cost analysis, but they are retained as separate interdealer market-structure evidence. The 2018-2025 customer-dealer ATS sample contains 27,199,280 pairs. Among them, 14,950,299 pairs, or 55.0 percent, have dealer-side ATS participation.

ATS participation is defined at the leg level. A leg is classified as ATS if the ATS indicator equals Y; blank, missing, or other values are treated as non-ATS. In the customer-dealer paired sample, ATS participation appears on the dealer leg rather than the customer leg. We therefore define the main ATS variable as dealer-side ATS participation.

The direction-specific ATS model is:

$$Y_{p,t} = \alpha + \sum_{d \in D} \beta_d 1\{Direction_p = d\} \times DealerATS_p + \theta' X_{p,t} + \gamma_{CUSIP(p)} + \delta_t + \varepsilon_{p,t},$$

Where $D = \{P - D, D - P, S - D, D - S\}$. The dependent variable $Y_{p,t}$ is the zero-spread indicator, absolute spread, positive-only spread, or winsorized positive-only spread. The coefficients β_d capture the association between dealer-side ATS participation and spreads for each pair direction.

To examine whether the ATS association changes after the post-2022 expansion of electronic execution, we estimate:

$$Y_{p,t} = \alpha + \sum_{(d \in D) \beta_d} 1\{Direction_p = d\} \times DealerATS_p + \sum_{(d \in D) \lambda_d} 1\{Direction_p = d\} \times DealerATS_p \times Post2022_t + \theta' X_p$$

The interaction coefficients λ_d summarize how the dealer-side ATS association changes after 2022 for each pair direction.

The empirical design is descriptive and diagnostic. The first part of the next two sections documents how liquidity fragility appears across price and non-price margins during major stress episodes. The second part examines whether dealer-side ATS participation is associated with direction-specific differences in paired-trade spreads. We do not interpret the ATS estimates as causal treatment effects, since dealers may choose ATS execution for particular bonds, trade sizes, inventory states, or customer contexts.

The data from 2005 to 2025 is summarized in Table 1; the descriptive statistics of bond variables is summarized in Table 2.

Table 1. Data summary and sample construction

Panel	Item	Value	Definition / Note
Market-wide transaction sample	Years covered	2005-2025	Raw MSRB/EMMA trade reports after annual cleaning
Market-wide transaction sample	Reported trades	215,773,158	All P, S, and D trades used for market-wide extensive margin
Market-wide transaction sample	Total par amount	\$71.17 trillion	Sum of reported par amount over 2005-2025
Market-wide transaction sample	Mean annual unique traded CUSIPs	514,653	Average across calendar years
Market-wide transaction sample	Maximum annual unique traded CUSIPs	597,950	Maximum across calendar years
Market-wide transaction sample	P / S / D trades	P=50,356,087; S=89,993,085; D=75,423,986	P: dealer buys from customer; S: dealer sells to customer; D: interdealer
Customer-dealer paired-trade sample	Paired observations	52,595,988	Pairs matched by CUSIP, trade date, and par amount
Customer-dealer paired-trade sample	Positive-spread pairs	38,813,488	73.8% of paired observations

Panel	Item	Value	Definition / Note
Customer-dealer paired-trade sample	Zero-spread pairs	13,782,500	26.2% of paired observations
Customer-dealer paired-trade sample	Time-gap equals zero	28,046,469	53.3% of paired observations
Customer-dealer paired-trade sample	Time-gap=0 and spread=0	8,895,469	16.9% of paired observations
ATS customer-dealer sample	Years covered	2018-2025	Used for dealer-side ATS analysis
ATS customer-dealer sample	Customer-dealer pairs	27,199,280	Directions P-D, D-P, S-D, and D-S
ATS customer-dealer sample	Dealer-side ATS pairs	14,950,299	55.0% of ATS sample pairs

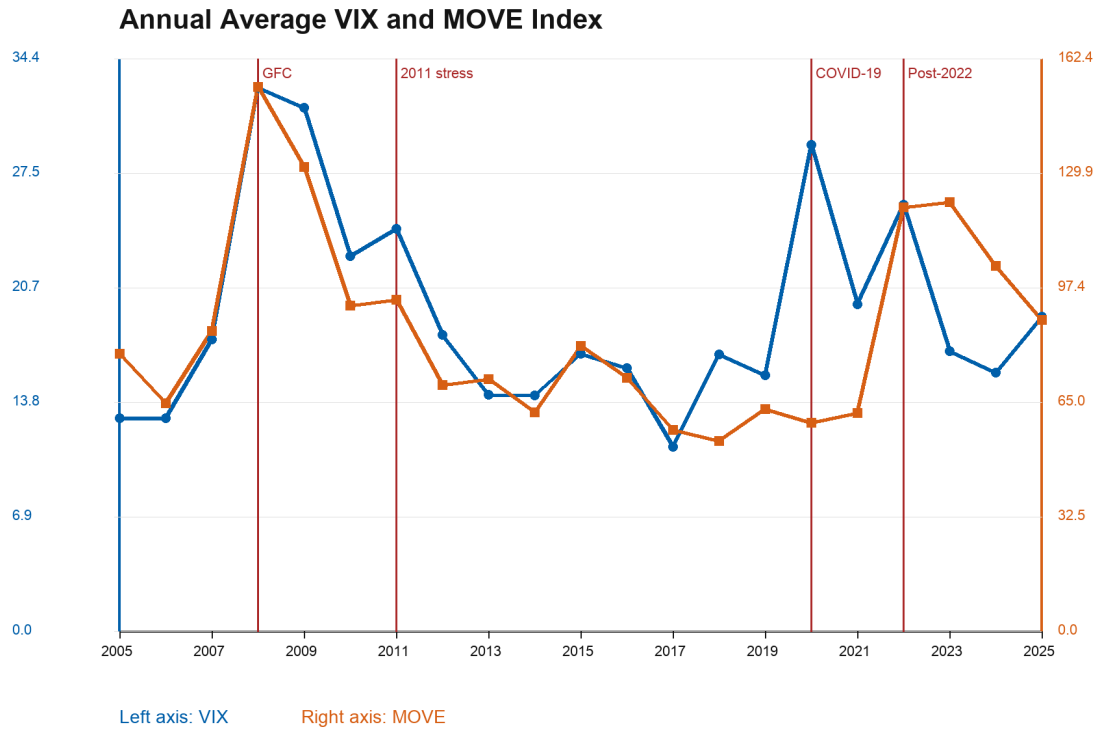
Table 2. Variable descriptive for the paired-trade sample, 2005-2025

Variable	Unit	Observations	Mean	Median	Std. Dev.	P25	P75
Term to maturity	Years	52,595,988	11.814	10.219	8.409	4.860	17.682
Coupon rate	Percent	52,595,988	4.362	5.000	1.210	4.000	5.000
Bond age	Years	52,595,988	5.061	4.463	4.111	1.901	7.397
Average pair price	Dollars per \$100 par	52,595,988	103.068	102.863	9.782	99.662	108.100
Par amount	U.S. dollars	52,595,988	96,613.195	25,000.000	679,232.655	15,000.000	50,000.000
Absolute paired-trade spread	Price points	52,595,988	0.549	0.163	0.732	0.000	0.950
Positive paired-trade spread	Price points; zero-spread pairs excluded	38,813,488	0.745	0.450	0.762	0.100	1.212
Time gap between legs	Seconds	52,595,988	623.000	0.000	2,536.310	0.000	37.000

4. Heterogeneous Liquidity Fragility Across Stress Episodes

This section studies how municipal bond liquidity fragility appears during major stress episodes. We focus on two episodes: the 2007-2009 global financial crisis and the COVID period. The two episodes are useful because they show different forms of fragility. The financial crisis is mainly a transaction-cost episode. COVID is more visible through market activity, paired-sample composition, matching, and the zero-spread mass.

Figure 1. Annual VIX and MOVE



We use two sets of outcomes. The first set comes from the market-wide transaction sample and captures the extensive margin of liquidity: trade count, par volume, unique traded CUSIPs, and average trades per CUSIP. The second set comes from the customer-dealer paired-trade sample and captures transaction-cost outcomes: pair count, positive-pair share, zero-spread rate, time gap, absolute spread, and positive-only spread. Separating these two samples is important. The market-wide sample shows whether the market continues to trade. The paired sample shows the cost and structure of customer-dealer intermediation among trades that can be matched.

Table 3. Event-window changes in market activity and paired-trade spreads

Episode	Window	Trade count change	Par volume change	Pair count change	Median positive spread change	Winsorized mean positive spread change	MOVE change
GFC	2007 to 2009	6.9%	-52.9%	34.6%	69.2%	25.0%	54.8%
COVID/20 21	2019 to 2021	-12.1%	-22.8%	-12.8%	-29.4%	-22.6%	-1.8%
Rate shock	2021 to 2023	71.5%	47.9%	83.9%	-20.0%	3.6%	96.7%

Episode	Window	Trade count change	Par volume change	Pair count change	Median positive spread change	Winsorized mean positive spread change	MOVE change
Post-2022 full	2021 to 2025	129.7%	69.0%	161.2%	-50.0%	-9.2%	42.8%

4.1 Market-Wide Stress and Paired-Trade Spreads

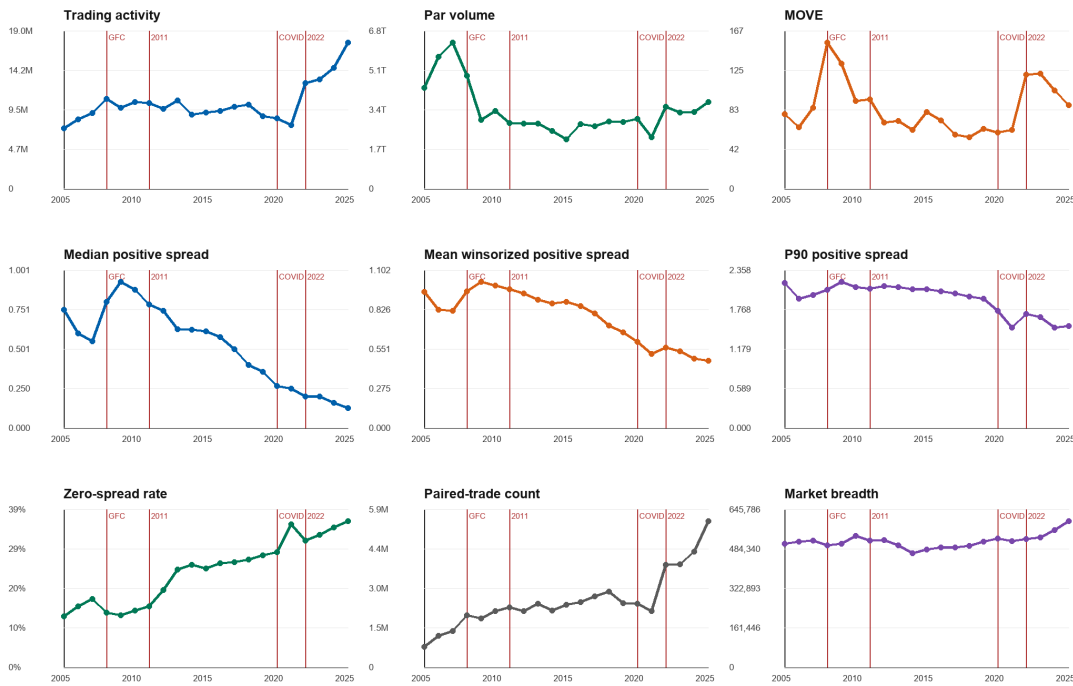
The long-run data show that municipal bond liquidity does not move on one margin. During some periods, trade counts rise while par volume falls. During others, paired spreads fall while the composition of matched trades changes. This is why transaction costs, activity, and matching diagnostics need to be interpreted together.

The global financial crisis stands out as the clearest case of transaction-cost fragility. From 2007 to 2009, market-wide par volume falls by 52.9 percent. At the same time, the median positive paired-trade spread rises by 69.2 percent, and the winsorized mean positive spread rises by 25.0 percent. This pattern indicates that the market remains active, but the cost of customer-dealer intermediation rises sharply. Dealers and customers continue to trade, but the price of immediacy becomes higher.

This pattern is consistent with the basic logic of liquidity fragility. When funding conditions tighten and volatility rises, dealers face higher inventory risk and greater difficulty placing bonds with offsetting counterparties. Customer trades can still clear, but they clear at worse terms. In this episode, the paired-trade spread is therefore an informative measure of liquidity stress.

Figure 2. Macro stress and paired-trade spreads

Macro Cycles, Liquidity Activity, and Paired-Trade Spreads



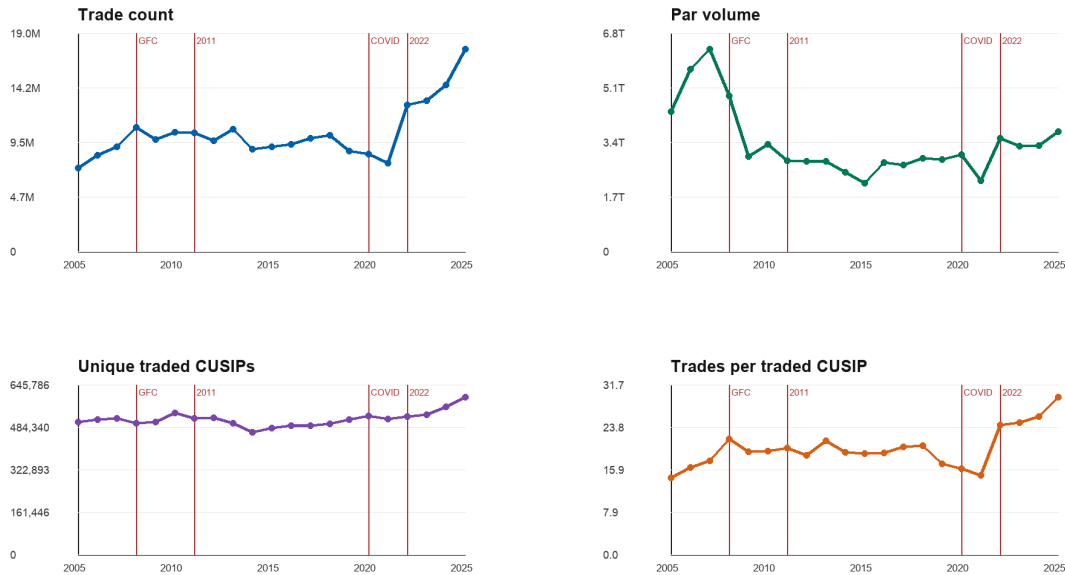
Spread measures use customer-dealer adjacent pairs with same CUSIP, trade date, and par amount. Zero-spread rate is diagnostic; positive and winsorized positive spreads are preferred transaction-cc

4.2 COVID and Extensive-Margin Fragility

COVID shows a different pattern. From 2019 to 2021, market-wide trade count falls by 12.1 percent, par volume falls by 22.8 percent, and the paired transaction-cost sample contracts by 12.8 percent. These changes indicate a decline in trading activity and in the set of trades that can be matched into the paired sample.

Figure 3. Market-wide extensive margin

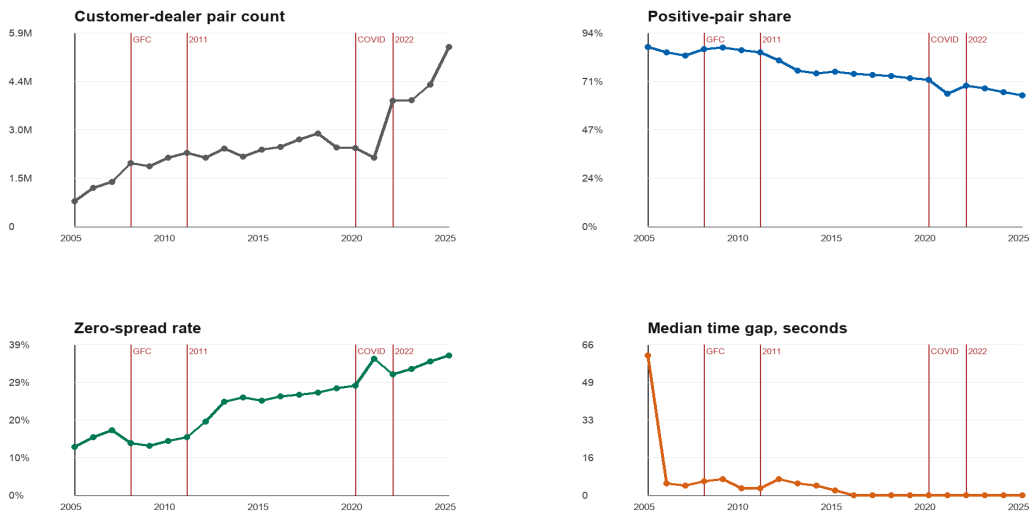
Market-Wide Extensive Margin, 2005-2025



However, positive-spread measures do not show the same deterioration. The median positive paired-trade spread falls from 0.354 to 0.250, and the winsorized mean positive spread falls by 22.6 percent. If liquidity fragility were measured only by positive-spread widening, the COVID episode would appear less fragile than the financial crisis. That interpretation would be incomplete.

Figure 4. Transaction-cost sample extensive margin

Transaction-Cost Sample Extensive Margin, 2005-2025



The COVID evidence suggests that fragility can appear through sample composition and the extensive margin. The trades that remain in the paired sample may be easier to match, more standardized, or more quickly intermediated. At the same time, more difficult trades may disappear from the matched transaction-cost sample or occur with lower par volume. In this case,

lower positive-spread medians do not necessarily imply better liquidity. They may reflect a change in which trades are observed.

4.3 Zero-Spread and Time-Gap Diagnostics

Zero-spread observations are important for interpreting the COVID period. In the full 2005-2025 paired sample, zero-spread pairs account for 26.2 percent of all pairs. The zero-spread share rises from 27.7 percent in 2019 to 35.3 percent in 2021. This increase occurs while market-wide activity and par volume fall.

We do not drop zero-spread pairs because they are part of the market structure. A zero spread may reflect same-price offsetting trades, dealer matching, electronic or interdealer execution, reporting conventions, or the composition of trades that remain easy to match. It should not be interpreted as literal zero economic friction, but it should also not be treated as a data error.

Time-gap diagnostics help clarify this point. In the full paired sample, 53.3 percent of pairs have a zero-second time gap, while 26.2 percent have zero spread. Only 16.9 percent have both zero time gap and zero spread. Thus, same-time matching and zero-spread matching are related but not identical. A zero time gap does not mechanically imply a zero spread, and a zero spread is not simply a byproduct of simultaneous reporting.

This matters for the interpretation of COVID. The rise in zero-spread mass during COVID is not evidence that transaction costs disappeared. It is evidence that the structure of matched trades changed. Combined with lower trade count, lower par volume, and a smaller paired sample, the zero-spread increase points to fragility in market composition and intermediation rather than in positive spreads alone.

Table 4. Time-gap and zero-spread diagnostics

Year	Pair count	Time gap = 0 share	Spread = 0 share	Both share	P(spread=0 gap=0)	Median positive spread, gap>0	Median positive spread, gap=0
all	52,595,988	53.3%	26.2%	16.9%	31.7%	0.565	0.250
2007	1,355,933	40.4%	16.8%	9.1%	22.5%	0.675	0.500
2009	1,825,223	40.8%	12.8%	6.3%	15.4%	0.933	0.915
2019	2,402,893	56.2%	27.7%	16.5%	29.3%	0.466	0.250
2021	2,096,513	60.6%	35.3%	24.5%	40.5%	0.390	0.128
2025	5,475,619	71.8%	36.1%	28.2%	39.3%	0.300	0.100

4.4 Summary of this Section

The evidence from the global financial crisis and COVID shows that municipal bond liquidity fragility is heterogeneous. During the financial crisis, fragility appears mainly through the price margin: positive paired-trade spreads rise sharply while par volume contracts. During COVID, fragility appears mainly through the extensive margin and matching structure: trade count falls, par volume falls, the paired sample contracts, and the zero-spread share rises even though positive-spread medians decline.

This result motivates the second part of the paper. If municipal bond liquidity is fragile partly because trading depends on search and dealer intermediation, then changes in electronic execution should matter. But the first part also suggests that the effect should not be summarized by a single market-wide liquidity measure. The next section therefore studies dealer-side ATS participation and asks whether its association with transaction costs differs across customer-dealer trade directions.

5. Dealer-Side ATS Participation and Search Frictions

This section studies whether the post-2022 expansion of Alternative Trading Systems (ATS) is associated with lower search frictions and transaction costs in the municipal bond market. The analysis focuses on customer-dealer paired trades from 2018 to 2025. The main point is that ATS participation is not a simple pair-level feature. In the customer-dealer paired sample, ATS appears on the dealer leg rather than the customer leg. We therefore study dealer-side ATS participation and interact it with trade direction.

5.1 ATS Sample and Dealer-Leg Participation

The ATS analysis uses 27,199,280 customer-dealer pairs from 2018 to 2025. The sample is restricted to four pair directions: P-D, D-P, S-D, and D-S. Pure D-D pairs are excluded from the main customer transaction-cost analysis because they represent interdealer market structure rather than customer-facing transaction costs. They are useful evidence on market design, but they should not be mixed with customer-dealer spreads.

Among the customer-dealer pairs, 14,950,299 pairs, or 55.0 percent, have dealer-side ATS participation. ATS participation appears on the dealer leg rather than on the customer leg. This fact shapes the empirical design. A simple ATS dummy would combine economically different cases. Instead, we define dealer-side ATS participation and examine how its association with spreads differs across P-D, D-P, S-D, and D-S directions.

5.2 Direction-Specific Spread Differences

The descriptive evidence shows that dealer-side ATS is associated with different spread patterns across directions. In P-D, D-P, and S-D pairs, dealer-side ATS is associated with lower positive-only spreads. The strongest pattern appears in S-D pairs. For S-D pairs, the positive-only median spread is 0.400 without dealer-side ATS and 0.200 with dealer-side ATS.

D-S pairs move in the opposite direction. For D-S pairs, the positive-only median spread is 0.250 without dealer-side ATS and 0.300 with dealer-side ATS. This difference is important because it shows that ATS participation should not be described as a uniform electronic-trading discount. Dealer-side ATS appears to matter differently depending on the sequence of customer and interdealer legs.

This direction-specific pattern is consistent with a search-friction interpretation. If ATS helps dealers locate counterparties, route trades, or manage inventory, its effect should depend on whether the dealer is buying from or selling to a customer and whether the interdealer leg occurs before or after the customer leg. The same electronic channel may reduce observed spreads in one direction and be associated with higher spreads in another direction if the underlying intermediation problem is different.

Table 5. Customer-dealer direction and dealer-side ATS, 2018-2025

Dir.	Dealer ATS	Pairs	Zero- spread rate	Positive- pair share	Median pos. spread	Winsorized mean pos. spread	Med. gap
D-P	No	1,830,355	55.7%	44.3%	0.250	0.336	0s
D-P	Yes	2,628,640	27.7%	72.3%	0.200	0.324	0s
D-S	No	3,861,205	30.3%	69.7%	0.250	0.656	6s
D-S	Yes	5,074,899	24.7%	75.3%	0.300	0.714	2s
P-D	No	2,837,959	50.8%	49.2%	0.200	0.331	0s
P-D	Yes	3,788,915	25.1%	74.9%	0.135	0.315	0s
S-D	No	3,719,462	28.9%	71.1%	0.400	0.750	0s
S-D	Yes	3,457,845	32.7%	67.3%	0.200	0.654	0s

5.3 Fixed-Effect Diagnostic Evidence

The fixed-effect evidence supports the direction-specific interpretation. Year-by-year models with CUSIP fixed effects and trade-date fixed effects show that the $S-D \times \text{dealer_ATS}$ coefficient is negative in every year. The association becomes more negative in the post-2022 period, especially in 2024 and 2025. This pattern appears in both positive-only spreads and winsorized positive-only spreads.

D-S is less stable before 2022 but moves in the opposite direction in the post period. The weighted post-2022 D-S coefficient is positive and larger than the pre-2022 coefficient. This result is consistent with the descriptive evidence that D-S pairs have higher positive-only spreads when the dealer leg is ATS.

The contrast between S-D and D-S is central to the interpretation. If ATS simply lowered transaction costs, the coefficient should have the same sign across directions. Instead, the estimates suggest that dealer-side ATS is related to the structure of intermediation. The association depends on whether the customer trade and interdealer trade occur in a direction where electronic execution helps dealer search and inventory placement, or in a direction where ATS participation reflects a different type of trade.

Table 6. Year-specific fixed-effect coefficients: pre/post weighted averages

Outcome	Dir.	Pre 2018-2021	Post 2022-2025	Post minus pre
Positive spread	D-P	-0.019	-0.058	-0.039
Positive spread	D-S	0.005	0.030	0.025
Positive spread	P-D	-0.003	-0.068	-0.065
Positive spread	S-D	-0.081	-0.103	-0.022
Winsorized positive spread	D-P	-0.016	-0.047	-0.031

Outcome	Dir.	Pre 2018-2021	Post 2022-2025	Post minus pre
Winsorized positive spread	D-S	0.004	0.028	0.025
Winsorized positive spread	P-D	-0.005	-0.069	-0.064
Winsorized positive spread	S-D	-0.083	-0.105	-0.022

Figure 5. Yearly coefficients for S-D and D-S

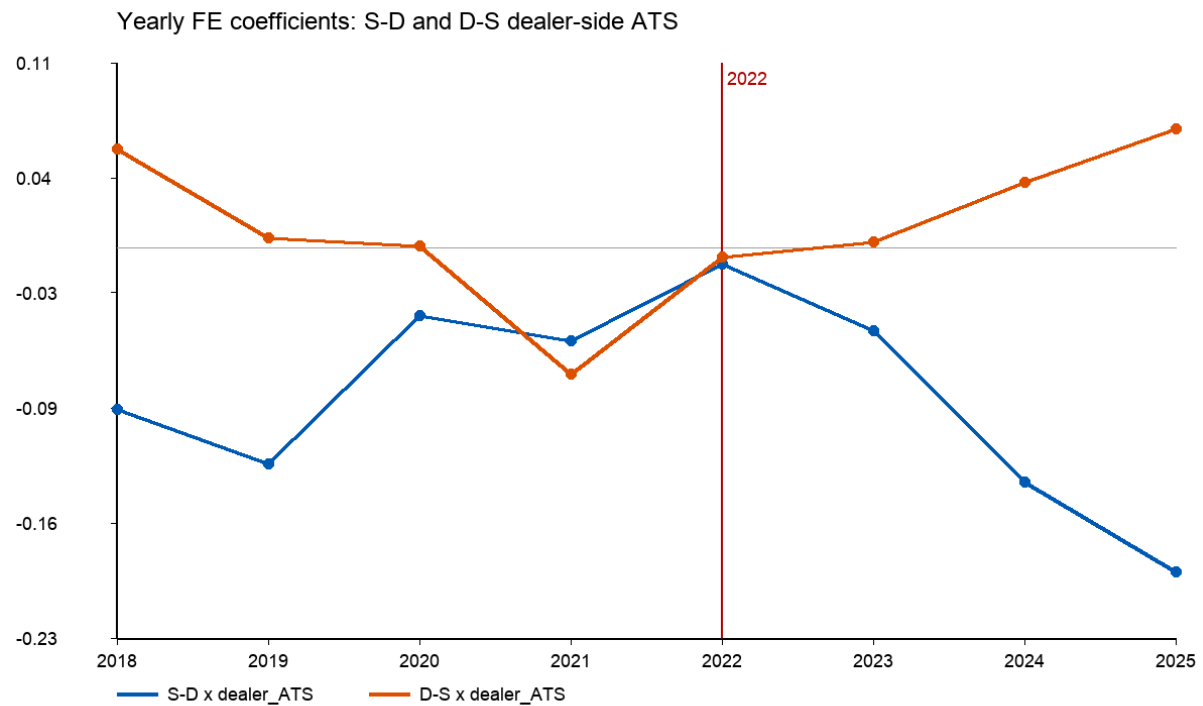
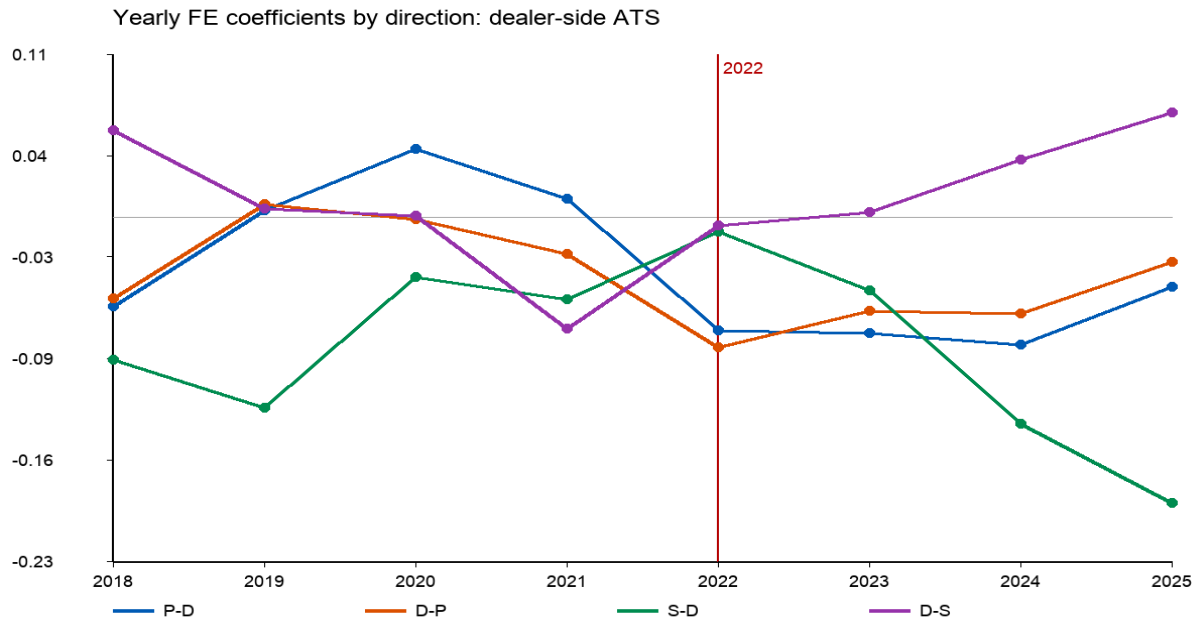


Figure 6. Yearly coefficients for all customer-dealer directions



5.4 Interpretation

The ATS results should be interpreted as diagnostic evidence, not as causal estimates. Dealers may choose ATS execution for particular bonds, trade sizes, inventory states, or customer contexts. Even with CUSIP and trade-date fixed effects, ATS participation is not randomly assigned.

The evidence nevertheless provides a useful market-structure result. Dealer-side ATS participation is associated with lower positive-only spreads in P-D, D-P, and especially S-D pairs, while D-S pairs move in the opposite direction. This means that the paper should not use a simple ATS dummy as the main specification. The more appropriate specification is a set of direction-specific dealer-side ATS interactions.

5.5 Summary of the Section

The post-2022 ATS evidence supports a direction-specific dealer-side electronic execution story. ATS appears on the dealer leg rather than the customer leg. Its association with transaction costs depends on pair direction. The strongest and most stable negative association appears in S-D pairs, while D-S pairs show the opposite pattern.

These findings connect back to the liquidity-fragility evidence in Section 5. Municipal bond liquidity depends on search and dealer intermediation. Electronic execution can change those frictions, but it does not do so uniformly. The effect depends on the trading direction and the role of the dealer in the matched transaction sequence.

6. Discussion and Conclusion

This paper studies liquidity fragility and electronic execution in the U.S. municipal bond market. The evidence points to two main conclusions. First, municipal bond liquidity fragility is heterogeneous. It does not appear only through wider transaction-cost spreads. Second, post-2022 electronic execution through ATS is associated with dealer-side and direction-specific spread differences, rather than with a uniform reduction in transaction costs.

The long-run evidence shows that different stress episodes affect municipal bond liquidity through different margins. During the 2007-2009 financial crisis, fragility appears mainly through the price margin. Market-wide par volume falls sharply, and positive customer-dealer paired spreads rise substantially. This is the conventional form of liquidity fragility: trades still occur, but immediacy becomes more expensive. The COVID episode shows a different pattern. Positive-spread medians do not widen. Instead, market-wide trade count falls, par volume declines, the paired transaction-cost sample contracts, and the zero-spread share rises. This does not mean that liquidity improves during COVID. Rather, it suggests that the composition of observable matched trades changes. In this setting, liquidity stress may appear through activity, sample composition, matching, and zero-spread mass, not only through higher observed spreads. This finding has an important measurement implication. Municipal bond liquidity should not be summarized by one spread statistic. Transaction-cost spreads are important, but they capture only one margin of liquidity. A full assessment should also examine trading activity, par volume, market breadth, paired-sample composition, time gaps, and zero-spread mass. This is especially important in a fragmented OTC market, where the absence or transformation of trades can be as informative as the price of observed trades.

The ATS evidence also has a measurement implication. A simple ATS dummy is too coarse. In the 2018-2025 customer-dealer paired sample, ATS participation appears on the dealer leg rather than the customer leg. Dealer-side ATS is associated with lower positive-only spreads in P-D, D-P, and especially S-D pairs, while D-S pairs move in the opposite direction. The strongest and most stable negative association appears in S-D pairs. This pattern suggests that electronic execution works through dealer-side search, routing, and inventory-management channels rather than through a uniform reduction in customer transaction costs.

The policy implication is not that municipal bonds should be forced into a fully standardized design. Brancaccio and Kang (2025) show that bond complexity and non-standard provisions can increase search frictions and give incumbent intermediaries an advantage, but municipal issuers also need flexibility in maturity structure, call features, repayment schedules, and project-specific financing. Our ATS results suggest a more targeted policy margin. The lower spreads in S-D pairs with dealer-side ATS are consistent with reduced search frictions in that trading direction. Regulators and market participants could therefore encourage ATS use and electronic search tools where they improve dealer-side matching, while preserving the financing and repayment flexibility that local governments need.

Overall, the evidence supports a market-structure interpretation of municipal bond liquidity. The municipal bond market is fragile not only because transaction costs can rise under stress, but also because trading activity, matching, and intermediation structure can change. Electronic execution may help reduce some search frictions, but its role is not uniform. It depends on the dealer's position in the transaction sequence and on the direction of customer-dealer intermediation. Future work can build on these findings by developing stronger identification strategies, examining dealer-level behavior, and studying how electronic execution affects customer welfare and municipal issuers' financing costs.

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