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Municipal Bond Liquidity and Default Risk

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ABSTRACT

This paper examines the pricing of municipal bonds. I use three distinct, complementary approaches to decompose municipal bond spreads into default and liquidity components, and find that default risk accounts for 74% to 84% of the average spread after adjusting for tax-exempt status. The first approach estimates the liquidity component using transaction data, the second measures the default component with credit default swap data, and the third is a quasi-natural experiment that estimates changes in default risk around pre-refunding events. The price of default risk is high given the rare incidence of municipal default and implies a high risk premium.

SINCE THE FINANCIAL CRISIS, the poor condition of local government finances has captured the attention of academics, legislators, and the popular press. Rising retirement and healthcare costs are straining state and local government budgets. The post-crisis spate of defaults by cities and counties, including the bankruptcy filing by Detroit in 2013, represents the most significant default episode in the municipal bond market since the Great Depression.[1] Based on recent events, it seems that municipal default risk is on the rise. However, a longer view reveals that defaults are extremely rare in the municipal bond market. The historical five-year cumulative default rate for all municipal bonds is 0.08% from 1970 to 2014, and the corresponding rate for general obligation bonds is 0.01% (Moody's (2015)).

The academic literature on municipal bonds focuses instead on tax effects and illiquidity as important issues in this market. Most municipal bonds are exempt from federal and state taxes, so the pricing of their cash flows relative to Treasuries has drawn interest (Green (1993), Ang, Bhansali, and Xing (2010), Longstaff (2011)). Trading is done over-the-counter and the tax exemption attracts retail investors as the primary clientele, resulting in high transaction

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[1] For a review of the history of municipal defaults, see Spiotto, Acker, and Appleby (2012) and Ang and Longstaff (2013).

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costs due to search frictions and dealer market power (Green, Hollifield, and Schurhoff (2007b), Green, Li, and Schurhoff (2010), Schultz (2012), Li and Schurhoff (2014)). Novy-Marx and Rauh (2011a, 2011b) draw attention to the dire condition of public pensions, but little work has been done on the pricing of default risk in the municipal bond market. In this paper I address the following question: what are the relative contributions of default risk and liquidity to the pricing of municipal bonds?

After adjusting for the tax exemption, I find that default risk accounts for 74% to 84% of the average municipal bond spread over the period 1998 to 2015. The average default spread of 101 bps and the extremely low historical default rate imply a default risk premium that is an order of magnitude larger than estimates of the risk premium in the corporate bond market (Berndt et al. (2005)). Investors in general obligation bonds receive between 78 bps and 126 bps of taxable-equivalent compensation per 1 bp of expected default loss.

To arrive at the above conclusions, I use three distinct approaches to decomposing municipal bond spreads. The first approach follows from Dick-Nielsen, Feldhutter, and Lando (2012) and estimates the liquidity component of the spread using the transaction data.[2] The second approach follows from Longstaff, Mithal, and Neis (2005) and measures the default component with credit default swap (CDS) spreads. The third approach is a quasi-natural experiment that studies the reaction of spreads to pre-refunding, an event that renders the bond risk-free until its call date (Fischer (1983), Chalmers (1998)). These complementary approaches lead to similar findings and mitigate concerns that any shortcomings associated with each approach are driving the results.

In this paper, I show that default risk plays an outsized role relative to the observed rate of default due to a high risk premium. I find that the role of liquidity is not as large as one might infer from the literature on transaction costs in the municipal bond market. Intuitively, the liquidity spread depends on the expected cost of trading and the expected trading intensity, or need to sell the bond. The typical investor in this market is a buy-and-hold retail investor, so trading intensity is low and the liquidity discount is small.[3]

These findings have policy implications that merit further exploration. My results imply that if policy makers wish to reduce the cost of financing state and local government investment, then efforts to reduce transaction costs and improve liquidity will not have a significant impact on borrowing costs. In contrast, reducing the default risk premium to the level of the risk premium in the corporate bond market would dramatically reduce municipal bond yields. One potential source of this risk premium is the tax exemption, which could operate through two channels. First, the tax exemption is unattractive to institutional

[2] Marlowe (2013) also uses the Dick-Nielsen, Feldhutter, and Lando (2012) approach to estimate the liquidity spreads of individual municipal bonds, but he focuses on the impact of the monoline insurer downgrade on liquidity spreads.

[3] At the end of 2015, \$1.6 trillion of the \$3.7 trillion bonds outstanding were owned directly by households, with another \$975 billion held by mutual funds on behalf of households (Federal Reserve Statistical Release Z.1, Table L.212).

investors with low marginal tax rates, which limits the supply of risk-bearing capital in the market. Second, most states exempt only local bonds from state income tax, leading to home bias and imperfect risk-sharing (Babina et al. (2015)).

This paper relates to the literature on the financial condition of state and local governments. Novy-Marx and Rauh (2011a, 2011b) show which states and local governments are in the worst financial condition due to pension underfunding, but there is little academic work on the bond market's assessment of state and local government default risk. I find that Detroit (pre-bankruptcy), Chicago, and Illinois have significantly higher default spreads than their peers, consistent with Novy-Marx and Rauh's (2011a, 2011b) results on pension underfunding. However, even the least creditworthy states and large cities trade at spreads similar to marginally investment grade corporate issuers, with Illinois priced like a BBB-rated corporate issuer and Detroit and Chicago priced close to BB-rated corporates.

Closely related to my work is a contemporaneous paper by Ang, Bhansali, and Xing (2014), who reach very different conclusions. They find that liquidity accounts for 74% of the average municipal bond spread. Their decomposition relies on computing synthetic risk-free municipal bond yields using an estimated zero-coupon curve from pre-refunded bonds. Importantly, they use separate pools of bonds that have been and have not been pre-refunded, with no controls for omitted issuer or bond-specific factors. My quasi-natural experiment with pre-refunded bonds, which focuses on within-bond changes in spreads and controls for bond and time-specific unobservables, shows that the pre-refunding event reduces the bond spread by at least 41%, assuming no offsetting effect from reduced liquidity.[4]

In another paper that uses pre-refunded bonds to control for noncredit factors, Novy-Marx and Rauh (2012) study the effect of state pension investment losses on state bond yields. In contrast to Ang, Bhansali, and Xing (2014), these authors compare bonds from the same issuer that have and have not been pre-refunded, rather than using a marketwide pool of pre-refunded bonds. The results in Novy-Marx and Rauh (2012) are consistent with my finding that default risk is the main driver of municipal bond spreads. They find that, between September 30 and December 31, 2008, the average non-pre-refunded bond spread increased by 116 bps, while the average pre-refunded spread increased by only 27 bps. Their triple-difference regression estimates imply that 48% of the differential spread increase for the average issuer can be attributed to the deterioration in state pension funding.

Wang, Wu, and Zhang (2008) also find that liquidity plays a secondary role to default risk in municipal bond pricing. They decompose municipal bond

[4] Ang, Bhansali, and Xing (2014) show that liquidity is significantly reduced after pre-refunding and impose a liquidity correction of 15 bps to 50 bps to compare pre-refunded and non-pre-refunded bond spreads. The average spread prior to pre-refunding is 211 bps, so using the liquidity adjustment from Ang, Bhansali, and Xing (2014) would increase the estimated contribution of default risk in my quasi-natural experiment to between 48% and 65%.

yields by estimating a structural model that generalizes Green's (1993) model of tax-exempt yields to include default and liquidity risk. My decomposition of municipal bond spreads improves on Wang, Wu, and Zhang (2008) in two important ways. First, my results are based on a model-free analysis of individual bonds that captures both the level of liquidity and liquidity risk, whereas Wang, Wu, and Zhang (2008) only study the exposure of rating category portfolios to a marketwide liquidity factor. Additionally, my sample covers the period 1998 to 2015, which includes the financial crisis and its aftermath, while their sample only covers the period 2000 to 2004.

The remainder of this paper is organized as follows. Section I describes the municipal bond transaction data. Section II outlines a simple model of municipal bond yields, and describes the three approaches to spread decomposition. Section III presents the results. Section IV discusses robustness. Section V concludes.

I. Data

The starting point for my sample is a comprehensive historical data set of municipal bond transaction prices from the Municipal Securities Rulemaking Board (MSRB) that covers the period January 1998 to June 2015. Since the start of 1998, the MSRB has required dealers to report all municipal bond transactions, including interdealer trades as well as purchases and trades from customers.[5] These reports include the bond CUSIP, the date and time of the trade, the transaction price and yield, the issue date and maturity of the bond, the coupon rate, and a categorical variable indicating whether the trade is a sale to a customer, a purchase from a customer, or an interdealer trade. The MSRB transaction data set includes 148,549,596 trades involving 3,105,459 distinct bonds.

I supplement the MSRB data with bond-specific information from Bloomberg, including issuer name, issuance size, the source of funds and use of proceeds, the bond's credit rating, whether the coupon is fixed or variable, the tax status of the coupon payments, callability and the first call date, insurance status and the identity of the insurer, and pre-refunding status and timing. In light of Bloomberg's download limits and because I am interested in the borrowing costs and default risk of economically important issuers, I focus on the general obligation (GO) bonds of states and large local governments.

I identify six-digit issuer CUSIPs for 42 states and collect header information from Bloomberg for all related CUSIPs.[6] I am unable to find GO bonds issued by the following states, which have laws prohibiting or limiting GO bond issuance:

[5] The MSRB required reporting of interdealer transactions over the period 1995 to 1997, but customer trades were not reported until 1998, so I exclude the 1995 to 1997 period from my study.

[6] The first six characters of a CUSIP are known as the base and uniquely identify the issuer. The seventh and eighth digits identify the exact issue. The ninth digit is an automatically generated checksum. I select one full CUSIP for each six-digit CUSIP and download the issuer name from Bloomberg. At this point, I identify by hand the six-digit CUSIPs for the GO bonds of each state.

Arizona, Colorado, Idaho, Indiana, Iowa, Kansas, Kentucky, Nebraska, North Dakota, South Dakota, and Wyoming.[7] I hand-match the state-level GO bond transaction sample with data on revenues, expenditures, and indebtedness for each state from the U.S. Census Bureau Annual Survey of State Government Finances, which covers the period 1942 to 2014. I also merge data on state GDP per capita from the U.S. Bureau of Economic Analysis. Finally, for some states, trading in CDS contracts has been initiated. I collect monthly CDS premium quotes from Bloomberg for all available states starting in January 2008, when the first quotes are available.

In addition to state bonds, I am interested in bonds issued by large cities and counties. I identify a sample of cities and counties using the U.S. Census Bureau Annual Survey of Local Government Finances. The Census data detail revenue, expenditures, and indebtedness for all cities and counties in the United States. Using total revenue as a proxy for the size of the local government, I select all cities and counties with at least \$50 million in average revenue during the available period for the Census data, which is 1951 to 2012 for cities and 1957 to 2012 for counties. Hand-matching six-digit issuer CUSIPs with this set of local governments results in transaction data for 339 cities and 405 counties. There are 81 cities and 72 counties that meet the revenue criterion but with which I am unable to match GO bonds.

Panel A of Table I summarizes each step of the sample construction. I clean the data using the procedure outlined in Green, Li, and Schurhoff (2010) to eliminate obvious data errors and obtain fundamental price estimates. First, if coupon and maturity information are missing for all trades in a bond, if the coupon is listed as greater than 20%, or if maturity is listed as over 100 years, I exclude all trades in that bond. I also drop all transactions where the price is less than 50 (i.e., 50% of face value), as these are likely to be data errors given the lack of extreme distress during this time period.[8] I drop a few observations for which prices are greater than 150 with a short time to maturity, as these are also likely to be errors. I additionally exclude trades that occur after the maturity of the bond, as these must be clerical errors, and I drop bonds for which there are fewer than 10 transactions, as these provide little information for my analysis.[9] The cleaned transaction data include 129,850,645 trades in 1,319,944 distinct bonds. After restricting attention to GO issuers identified

[7] The state constitutions of CO, IN, NE, and ND prohibit these states from issuing GO debt. The state constitutions of ID, IA, and WY allow GO issuance with voter approval, but these states have no GO debt outstanding. AZ's constitution places a cap of \$350,000 on GO issues. KS's constitution allows limited issuance of GO bonds, but the state has not issued any GO debt in decades. KY's constitution requires voter approval for GO issuance, but this state has not issued any GO debt since 1966. SD's constitution places limits on indebtedness and the state has no outstanding GO debt. See http://www.tre.wa.gov/documents/debtCommissionStateDebtLimits100411.pdf.

[8] I hand-checked the prices that are excluded by this restriction and none of them correspond to issuers that should have traded at extremely high yields.

[9] Because the MSRB data include the initial sale of the bond, which involves the underwriter selling it in blocks to investors, the 10-transaction threshold is a low bar to clear.

Table I
Sample Construction

This table summarizes the construction of the municipal bond transaction sample. Panel A describes the steps involved in cleaning the transaction data. The Census match step restricts the sample to general obligation bonds from states, cities, and counties with annual revenues over $50 million. The removal of data errors involves dropping bonds with missing information in the MSRB data, coupons greater than 20%, maturities over 100 years, and fewer than 10 trades in the sample period, as well as individual trades occurring at prices below 50 and above 150. See Section I for a description of the remaining steps of the sample construction. Panel B describes the distribution of bond characteristics and transaction sizes. Panel C reports the proportion of transactions falling under different categories.

Panel A: Steps to Cleaning Transaction Data

Cleaning Step	Bonds	Trades
Full MSRB sample	3,105,459	148,549,596
Remove data errors	1,319,944	129,850,645
Census match	133,079	16,906,318
Drop variable rate bonds	132,397	16,691,182
Drop insured bonds	77,442	10,527,863
Drop pre-refunded bonds	67,818	9,277,663
Drop taxable and AMT bonds	64,381	8,460,582
Exclude last year before maturity	63,533	7,868,733
Exclude three months after issuance	61,283	6,137,212
Drop callable bonds	33,642	2,526,279
Final sample	33,642	2,526,279

Panel B: Bond Characteristics

	Mean	StDev	p_1	p_{10}	p_{50}	p_{90}	p_{99}
Years to Maturity	4.61	2.64	1.06	1.58	4.15	8.19	12.5
Years since Issuance	5.00	4.46	0.31	0.92	3.82	10.7	21.3
Coupon Rate (%)	4.41	1.60	0	2.75	5.00	5.50	7.50
Issue Amount ($MM)	19.4	28.5	0.37	1.53	10.0	48.1	137
Transaction Amount ($000s)	228	1101	5.00	10.0	40.0	300	4715

Panel C: Categorical Bond Characteristics

	AAA	AA	A	BBB	$\leq$ BB	NR	
Rating Category (%)	29.8	53.7	15.6	0.63	0.06	0.04	
	CA	NY	MD	NC	MA	TX	OH
State (%)	12.2	11.4	6.74	5.81	5.67	5.36	5.18
	State	City	County				
Government Level (%)	58.8	23.6	17.6				

from the Census data, the sample is reduced to 16,906,318 trades in 133,079 bonds.

For the analysis in this paper, it is best to use bonds with similar contract terms. To simplify yield calculations, I restrict the sample to fixed-coupon bonds. I exclude insured bonds from the sample because I am interested in the underlying credit risk of municipal issuers, not the joint credit risk of issuers and insurers. I remove bonds that are pre-refunded from the sample because they are essentially risk-free after the refunding.[10] To ensure similar tax treatment, I remove bonds that are federally taxable or that are eligible for the alternative minimum tax (AMT). I exclude trades with less than a year to maturity because, at short maturity, small price deviations lead to large changes in yield. Newly issued municipal bonds exhibit high markups and large intraday price dispersion, so I exclude the first three months of prices after a bond is issued.[11] Finally, I drop callable bonds from the sample to avoid the complication of embedded options. The final sample consists of 2,526,279 trades in 33,642 bonds.

Panels B and C of Table I report summary statistics for the sample of municipal bond transactions. The typical bond has 4.6 years to maturity and has been outstanding for 5.0 years. Of the transactions, 99% have less than 12.5 years to maturity, due in part to the restriction to noncallable bonds. Including callable bonds increases the average time to maturity to 10.3 years but does not have a material impact on the main results. Issue sizes are small relative to other public debt markets, with the average and median bonds having \$19.4 million and \$10.0 million outstanding at issuance, respectively. Transaction sizes are commensurately small, with half of transactions less than \$40,000 in terms of principal amount. This reflects the prominence of retail investors in the municipal bond market. Most of the bonds are highly rated by Moody's and S&P at issuance, with 30% in the AAA category and 54% in the AA category. California is the most represented state with 12.2% of the transactions, followed by New York (11.4%), Maryland (6.7%), North Carolina (5.8%), and Massachusetts (5.7%). State bonds account for 58.8% of the trades in my sample, while cities and counties represent 23.6% and 17.6% of the trades, respectively.

Municipal bonds trade infrequently and intraday price variation can be large relative to movements in fundamentals, due to differences in terms of trade across investor types (Green, Hollifield, and Schurhoff (2007b)). The measures of illiquidity estimated in this study use the transaction data directly, but to estimate issuer credit spreads it is necessary to smooth transaction prices so that intraday price swings are not reflected in spreads. Following Green, Li, and Schurhoff (2010), I construct daily "fundamental prices" by taking the midpoint of the highest price on customer sales and the lowest price on customer purchases on each day. If customer sales and purchases are not both observed on a given day, then the daily fundamental price is the mean price of interdealer trades. If neither method yields a fundamental price, then I drop the observation from the analysis.

[10] Section II.E describes a quasi-natural experiment that estimates the pricing impact of pre-refunding using a separate sample of pre-refunded bonds.

[11] See Green, Hollifield, and Schuroff (2007a) and Schultz (2012). Schultz (2012) documents that price dispersion in the days after issuance declines dramatically after the introduction of 15-minute trade reporting by the MSRB in 2005. However, markups remain high and increasing in the days after issuance. For consistency, I use the same exclusion policy for the pre- and post-2005 periods.

II. Methods

This section describes the methods I use to decompose municipal bond spreads. I begin by discussing the factors driving the pricing of municipal debt. I then translate tax-exempt yields into taxable yields for comparison with CDS premia and swap rates. Next, I describe three distinct approaches to decomposing tax-adjusted spreads into default and liquidity components. The first approach is based on Dick-Nielsen, Feldhutter, and Lando (2012) and uses transaction data to estimate the liquidity component. The second approach is based on Longstaff, Mithal, and Neis (2005) and uses CDS data to measure the default component. The third approach is a quasi-natural experiment that uses changes in the spread around pre-refunding events to set a lower bound on the default component.

A. Components of Municipal Bond Yields

The yield spread between defaultable bonds and risk-free bonds depends on the likelihood of default, the expected loss given default, and less obviously, on the market price of credit risk, which determines the mapping from physical to risk-neutral probabilities of default. Two additional factors also contribute to municipal bond yields. First, most municipal bonds are exempt from taxes at the federal and state levels, which drives a wedge between the yields of tax-exempt and comparable taxable bonds. Second, municipal bonds are traded over-the-counter and are primarily held by retail investors, so substantial search costs are incurred when investors try to sell bonds on the secondary market. This suggests that liquidity should affect the pricing of municipal bonds. Taking these considerations into account, I express the yield on a tax-exempt municipal bond as

$$y_{i,t} = (1 - \tau_{s,t})(r_t + \gamma_{j,t} + \psi_{i,t}), \tag{1}$$

where i denotes the bond (identified by CUSIP), j the issuer, s the state in which the issuer is located, and t the time period. The factor $(1 - \tau_{s,t})$ reflects the wedge between tax-exempt and taxable yields. The parameter r_t represents the risk-free rate, $\gamma_{j,t}$ represents the default risk of the issuer, and $\psi_{i,t}$ represents compensation for illiquidity.

The marginal tax rate for investors in state s is denoted by $\tau_{s,t}$ and is assumed to be the same for all bonds issued within the state due to market segmentation. In most states, only coupon payments on bonds from within-state issuers are exempt from state taxation. Thus, ignoring diversification benefits, it is optimal for individual investors to concentrate their municipal bond holdings on within-state issuers.[12]

I measure the risk-free rate r_t using the interpolated maturity-matched swap rate. The swap rate is an appropriate benchmark for my purposes because it

[12] Schultz (2012, p. 494) notes that "the municipal bond market may be thought of as numerous loosely integrated state markets for municipal bonds."

is the benchmark for quoting CDS spreads and it is unaffected by the special collateral benefits that push Treasury yields below the risk-free rate (Feldhutter and Lando (2008)). The Internet Appendix shows that the main results are similar if the yield on a bond with the same cash flows discounted using the zero-coupon off-the-run Treasury curve (Gurkaynak, Sack, and Wright (2007)) is used as the risk-free benchmark instead.[13]

The default risk of issuer j is represented by the parameter $\gamma_{j,t}$. This term impounds both the default intensity and the loss given default of the issuer's bonds. I focus on GO bonds because they are claims on the taxing power of the issuer, rather than on a specific revenue stream, so all GO bonds should receive equal treatment in a bankruptcy or restructuring. This allows me to assume that both the probability of default and the expected loss given default are the same for all bonds from an issuer.

The liquidity spread or convenience yield is denoted by $\psi_{i,t}$. This spread reflects both expected transaction costs over the holding period of the bond and the risk that transaction costs increase over the holding period. Liquidity is an important pricing consideration in the municipal bond market, as most bonds are held by retail investors, so it is more difficult for dealers to locate buyers and sellers than in the Treasury and corporate bond markets, which are dominated by institutional investors. While costs are high for each individual transaction, the expected number of transactions for a municipal bondholder may be lower than for corporate bondholders, as municipal bonds are often owned by buy-and-hold retail investors.

B. Tax Adjustment

A small literature studies the marginal tax rate implied by municipal bond prices. Longstaff (2011) uses municipal swap market data to identify the marginal tax rate implied by one-week tax-exempt rates. He estimates a marginal tax rate close to the top statutory rate from 2001 to 2006, above the top rate in 2007, and well below the top rate, at around 10%, during the financial crisis. Kueng (2015) uses the AAA-rated GO yield curve to recover the term structure of implied income tax rates and finds that municipal bond yields reflect expected changes in income tax rates. He estimates that short-term implied rates are slightly below the top statutory rate and long-term implied rates are significantly lower.[14]

Data limitations prevent me from estimating the marginal tax rate jointly with the default and liquidity parameters, so I assume that the marginal tax rate impounded in tax-exempt bond yields is the top statutory income tax rate in each state. This is in line with the pre-crisis results in Longstaff (2011)

[13] The Internet Appendix is available in the online version of this article on the *Journal of Finance* website.

[14] Ang, Bhansali, and Xing (2010) exploit the tax treatment of market discount bonds to estimate implied income tax rates of 100% for retail trades and 70% for interdealer trades, but their analysis focuses on a subset of secondary market trades.

and the short-term estimates in Kueng (2015). Under this assumption, the tax adjustment factor is

$$1-\tau_{s,t}=\left(1-\tau_t^{fed}\right)\left(1-\tau_{s,t}^{state}\right), \tag{2}$$

where τ_t^{fed} is the top federal income tax rate and $\tau_{s,t}^{state}$ is the top income tax rate in state s in year t.[15] This formula accounts for the fact that state income tax payments are deductible from an individual's taxable income for federal taxes. Applying this tax adjustment factor and subtracting out the risk-free rate, the tax-adjusted spread on a tax-exempt municipal bond is

$$y_{i,t}^{TA}-r_t=\frac{y_{i,t}}{1-\tau_{s,t}}-r_t=\gamma_{j,t}+\psi_{i,t}. \tag{3}$$

The tax-adjusted spread depends on the default risk of the issuer and the liquidity of the bond. The primary aim of this paper is to decompose tax-adjusted spreads into these default and liquidity components.

This simple approach to adjusting for taxation is not necessarily the correct one, but it is likely close at short maturities. In the Internet Appendix, I consider two alternative tax adjustments. The first accounts for cyclicality in the marginal tax rate, applying the simple approach with Longstaff's (2011) marginal tax rate for the federal tax rate and the top statutory rate for the state tax rate. The second accounts for term structure effects on the marginal tax rate, applying Green's (1993) model to derive a tax adjustment that is smaller at long maturities, which reflects the incentive for taxable investors to shield coupon income from taxation. The two alternative tax adjustments lead to different levels of tax-adjusted spreads but similar proportional decompositions into default and liquidity components.

C. Transaction-Based Approach

The goal of this paper is to decompose tax-adjusted spreads into default and liquidity components. The first decomposition approach is closely related to the approach to estimating corporate bond liquidity spreads in Dick-Nielsen, Feldhutter, and Lando (2012). This approach involves estimating the liquidity spread directly and attributing the remaining spread to default risk. It has the benefit of being applicable to the full sample of transaction data, as it does not rely on external data on credit derivatives, as in the CDS-based approach.

Dick-Nielsen, Feldhutter, and Lando (2012) estimate liquidity spreads for corporate bonds sorted by time to maturity and credit rating, and find that the liquidity component of corporate bond spreads is substantial, particularly for speculative-grade bonds in times of crisis. Their estimation strategy is to construct a composite measure of liquidity, drawing on the literature on stock

[15] During my sample period, the top federal income tax rate was 39.6% from 1995 to 2000, 39.1% in 2001, 38.6% in 2002, 35% from 2003 to 2012, and 39.6% from 2013 to 2015. State tax rates ranged from zero in several states to 13.3% in California in 2015.

and bond liquidity, and then estimate the sensitivity of corporate bonds to this measure, controlling for credit risk. They obtain the liquidity spread for a maturity-rating category by multiplying this sensitivity by the difference between the median liquidity factor in a given maturity-rating category and the liquidity factor of a relatively liquid bond. I outline my version of this approach here.

The liquidity spread on a municipal bond is nontraded and unobservable, so I estimate it using several empirical proxies for liquidity. Following Dick-Nielsen, Feldhutter, and Lando (2012), my set of liquidity variables includes the Amihud (2002) measure and its standard deviation, the imputed round-trip cost (Feldhutter (2012)) and its standard deviation, and the Roll (1984) measure. I supplement these with trading activity variables including turnover, issuer zero-trade days, and trades per day. In addition, following Friewald, Jankowitsch, and Subrahmanyam (2012), I include the price dispersion measure (Jankowitsch, Nashikkar, and Subrahmanyam (2011)) in the set of liquidity variables and the average interval between trading days in the set of trading activity variables.

The liquidity and trading activity variables are described in the Appendix. The liquidity metrics are designed to capture expected transaction costs through price impact and effective bid-ask spreads, as well as the risk of these costs increasing. Given the over-the-counter structure of the municipal bond market, these variables are driven by search costs and dealer market power. The trading activity variables measure the trading intensity in the market for each bond.

I estimate the liquidity and trading activity variables on a monthly basis for each bond, winsorizing the liquidity variables at the 1^{st} and 99^{th} percentiles to mitigate the impact of outliers. Summary statistics for the liquidity and trading activity variables are presented in Panel A of Table II. The median Amihud (2002) price impact is 3.34% on a \$1 million trade and the median imputed round-trip cost is 0.31%. The distributions of both variables are positively skewed, consistent with the presence of many small retail trades. The median bond-month observation contains 11 trades, while the median interval between trade dates is 7.7 days. Overall, the summary statistics for the liquidity and trading activity variables are consistent with high transaction costs and infrequent trading in the municipal bond market.

I perform principal components analysis of the liquidity and trading activity variables to better understand their structure and to reduce dimensionality. Panel B of Table II presents the results of this analysis. The first principal component is approximately an equal-weighted average of the liquidity variables. Based on the first principal component, I define the liquidity measure λ for bond i in month t as

$$\lambda_{i,t} = \sum_{k=1}^{6} \frac{L_{i,t}^{k} - \mu^{k}}{\sigma^{k}}, \tag{4}$$

Table II

Liquidity Summary Statistics and Principal Components Analysis

This table reports statistics on the liquidity and trading activity variables, which are described in the Appendix. Statistics are based on 40,495 monthly observations for individual bonds. Panel A reports summary statistics. Panel B reports the results of a principal components analysis. The principal components analysis is performed on the correlation matrix, which accounts for different variances among the variables. The reported values are standardized scoring coefficients scaled up by a factor of 100.

Panel A: Summary Statistics

	Mean	StDev	p_1	p_{10}	p_{50}	p_{90}	p_{99}
Liquidity Variables							
Amihud Measure (% per $million)	9.79	19.7	0.02	0.31	3.34	23.2	122
Imputed Round-Trip Cost (%)	0.45	0.46	0	0.05	0.31	0.99	2.42
Price Dispersion	0.31	0.25	0.02	0.07	0.25	0.62	1.21
Roll Measure	1.01	0.79	0	0.21	0.82	2.03	3.92
Amihud Risk (%)	12.8	23.0	0.02	0.33	4.47	32.1	146
Round-Trip Cost Risk (%)	10.5	56.8	0.02	0.31	3.24	22.4	109
Trading Activity Variables							
Turnover (%)	22.0	51.3	0.30	1.03	5.63	53.8	256
Trades per Month	14.6	12.3	5	6	11	25	62
Trade Interval	16.1	31.5	1.63	3.09	7.67	32.2	146
Issuer Zero Trade	0.38	0.15	0.23	0.27	0.33	0.63	0.90
Turnover (Dealer Trades) (%)	8.63	25.4	0.05	0.23	1.67	18.9	125

Panel B: Principal Components Analysis

	1PC	2PC	3PC	4PC	5PC
Amihud Measure	24.1	13.6	0.26	25.2	−1.84
Imputed Round-Trip Cost	23.4	−2.93	11.0	−29.4	−3.76
Price Dispersion	24.2	−6.27	9.64	−32.0	−1.82
Roll Measure	20.3	−6.63	6.46	−35.3	−3.84
Amihud Risk	22.3	4.80	2.65	25.4	−2.33
Round-Trip Cost Risk	14.0	14.0	2.74	71.4	7.91
Turnover	−7.21	3.68	70.9	13.6	−11.1
Trades per Month	−1.51	−44.4	48.8	7.66	13.5
Trade Interval	−2.21	46.9	20.5	−21.0	85.9
Issuer Zero Trade	−4.45	48.0	21.4	−14.8	−73.2
Cumulative % Explained	34.5%	48.9%	60.6%	70.2%	77.8%

where L^k is one of the six liquidity metrics (Amihud, round-trip cost, price dispersion, Roll measure, Amihud risk, round-trip cost risk), and means μ and standard deviations σ are calculated over the full sample.

The second principal component resembles an average of the trade interval, the issuer zero-trade measure, and the negative of trades per month. Higher values of the second principal component correspond to less frequent transactions. The third principal component loads heavily on turnover. Dick-Nielsen, Feldhutter, and Lando (2012) limit attention to the first principal component in their analysis of the corporate bond market. Nevertheless, it is possible that liquidity is priced differently in the municipal bond market. With this in mind, I define the trading activity measure λ^T as

$$\lambda_{i,t}^T = \sum_{k=1}^{3} \frac{T_{i,t}^k - \mu^k}{\sigma^k}, \tag{5}$$

where T^k is one of the trading metrics loading in the second principal component (trade interval, issuer zero-trade, negative of trades per month). I approximate the third principal component using normalized turnover.

To estimate the effects of liquidity and trading activity on bond spreads, I estimate panel regressions of tax-adjusted spreads on these liquidity and trading activity composites:

$$y_{i,t}^{TA} - r_t = \alpha + \beta^{\lambda}\lambda_{i,t} + \beta^{\lambda^T}\lambda_{i,t}^T + \beta^{Turnover} Z(Turnover_{i,t}) + Rating_{i,t} + \epsilon_{i,t}, \tag{6}$$

where *Rating* includes dummies for each rating category present in the data (AAA, AA, A, BBB, BB and below, NR). I use the most recent S&P rating on the bond when available and use the Moody's rating when S&P does not rate the bond.[16] These credit rating controls mitigate omitted variable bias that would otherwise be present if there is any correlation between liquidity and creditworthiness.[17]

Table III reports the panel regression estimates. Column (1) shows that the credit rating dummies explain 17% of the variation in tax-adjusted spreads and that high credit ratings imply low yield spreads. Column (2) shows that the liquidity variable λ has significant power for explaining tax-adjusted spreads, as the R^2 increases from 17% to 29%. The positive coefficient on λ is highly significant and is consistent with higher trading costs implying higher yield spreads.[18] Columns (3) and (4) add the trading activity variable λ^T and normalized turnover to the set of explanatory variables. These variables add minimal explanatory power to the regression, although the coefficients on λ^T are significant.[19]

[16] I use the most recent ratings available for each bond, so they do not change over the time series and are sometimes forward-looking. This may cause measurement error for some bonds. However, rating transitions are infrequent for the GO bonds of large issuers, so this is not a major concern.

[17] The Internet Appendix contains a table showing that the addition of issuer debt-to-revenue and state GDP per capita as controls does not add explanatory power nor does the addition of those controls materially affect the coefficients on the liquidity and trading activity variables.

[18] The Internet Appendix contains a robustness check that verifies that the coefficient β_t^{λ} is driven by liquidity rather than unobserved credit risk. Following Dick-Nielsen, Feldhutter, and Lando (2012), I pair bonds from the same issuer, in the same month, with maturities less than one year apart. I regress the tax-adjusted spread on λ, including pair fixed effects to control for unobserved credit risk, and find highly significant coefficients on λ and the individual liquidity metrics. I thank Peter Feldhutter for recommending this exercise.

[19] The lack of improvement in explanatory power is not driven by the sequence of covariate inclusion. The Internet Appendix contains a table showing that the addition of only λ^T or normalized turnover to the credit rating dummies results in no impact on the R^2.

Table III

Liquidity Pricing Regressions

This table reports regressions of tax-adjusted yield spreads on liquidity and trading activity factors. The dependent variable is the tax-adjusted spread, which equals the tax-adjusted yield to maturity minus the interpolated maturity-matched swap rate. The liquidity variable $Z(\lambda)$ is the normalized sum of the six normalized liquidity measures and is designed to mimic the first principal component of the liquidity and trading activity variables. The trading activity variable $Z(\lambda^T)$ is the normalized sum of normalized issuer zero-trade days and normalized trading interval minus normalized trades per month, approximating the second principal component. $Z(Turnover)$ is the normalized turnover and proxies for the third principal component. The rating variables are dummies equal to one if the bond is in that rating category. The missing category includes the nonrated bonds. Month fixed effects are included in the last specification. t-statistics based on standard errors clustered by bond and month are reported in brackets. *, **, and *** indicate that the corresponding p-values are less than 0.05, 0.01, and 0.001, respectively.

Tax-Adjusted Spread	(1)	(2)	(3)	(4)	(5)
$Z(\lambda_{i,t})$		34.3***	34.4***	34.9***	29.4***
		[28.6]	[29.2]	[28.5]	[35.1]
$Z(\lambda^T_{i,t})$			−7.40***	−7.23***	−4.18***
			[−4.97]	[−4.89]	[−4.73]
Z(Turnover)				2.45**	−0.13
				[3.32]	[−0.33]
AAA-Rated	−245***	−175*	−175*	−174*	−173**
	[−5.73]	[−2.41]	[−2.42]	[−2.41]	[−3.01]
AA-Rated	−222***	−155*	−157*	−156*	−152**
	[−5.21]	[−2.15]	[−2.18]	[−2.16]	[−2.65]
A-Rated	−152***	−95.4	−102	−101	−97.3
	[−3.59]	[−1.33]	[−1.42]	[−1.40]	[−1.71]
BBB-Rated	−141**	−93.7	−90.5	−90.3	−96.1
	[−3.15]	[−1.28]	[−1.23]	[−1.23]	[−1.64]
BB-to-D-Rated	74.0	103	102	103	109
	[1.73]	[1.42]	[1.41]	[1.42]	[1.90]
Constant	345***	284***	286***	285***	318***
	[8.06]	[3.92]	[3.95]	[3.94]	[5.55]
Month FEs					X
R^2	0.17	0.28	0.29	0.29	0.51
Observations	37,931	37,931	37,931	37,931	37,931

The economic magnitude of the effect of liquidity on pricing is significant, with a one-standard-deviation increase in λ corresponding to an increase in the tax-adjusted spread of 0.43 standard deviations. The addition of month fixed effects in column (5) results in the coefficient on λ declining by 17%, the coefficient on λ^T declining by 40%, and the coefficient on normalized turnover becoming insignificant. The interpretation is that 17% (40%) of the yield spread loadings on liquidity (trading activity) are due to aggregate changes in transaction costs and trading intensity, while the remaining loadings are due to cross-sectional differences among bonds. Interestingly, the negative coefficient on λ^T implies that lower trading activity (higher λ^T) correlates with lower tax-adjusted spreads. This is consistent with models in the spirit of Amihud and Mendelson (1986) in which the liquidity discount is increasing in transaction costs and trading intensity. The positive coefficient on normalized turnover runs counter to this intuition, but this coefficient is not robust to controlling for time effects.

The Internet Appendix includes an alternative specification in which separate regressions are estimated for the three rating categories that make up the bulk of the sample: AAA, AA, and A. The coefficient estimates on λ and the low explanatory power of λ^T and turnover are quite similar across rating categories. The coefficient on λ^T is more significantly negative for lower-rated bonds, implying that low trading intensity corresponds to a smaller liquidity discount for less creditworthy issuers. Overall, the results in Table III are not materially impacted by the choice to pool observations in each quarter and control for rating category.

Based on the estimates in Table III, I exclude the trading activity variables from the decomposition and focus on the liquidity variable λ, in line with Dick-Nielsen, Feldhutter, and Lando (2012). The following regression describes the conditional relation between tax-adjusted spreads and the liquidity variable λ:

$$y_{i,t}^{TA} - r_t = \alpha + \beta_t^{\lambda}\lambda_{i,t} + Rating_{i,t} + \epsilon_{i,t}. \tag{7}$$

I use the 1st percentile of the liquidity variable, labeling it λ_{1p}, to benchmark the liquidity of a very liquid municipal bond. The liquidity spread is then estimated as

$$\psi_{i,t} = \beta_t^{\lambda}(\lambda_{i,t} - \lambda_{1p}). \tag{8}$$

Intuitively, the liquidity spread is increasing in both the liquidity composite $\lambda_{i,t}$ and the sensitivity of spreads to liquidity β_t^{λ}. With the liquidity spread in hand, I estimate the default spread as the remaining portion of the yield spread

$$\gamma_{i,t} = y_{i,t}^{TA} - r_t - \psi_{i,t}. \tag{9}$$

While ratings capture some of the differences in credit risk among different bonds, there is variation in credit risk that these dummies do not control for. Liquidity and default risk may be positively correlated, for instance, because information asymmetry leads market-makers to require a higher bid-ask spread when trading risky bonds. In that case, residual credit risk not captured by the rating dummies is subsumed by the coefficient β_t^{λ}, biasing it upward. On the other hand, if the liquidity composite λ is measured imprecisely, the bias could go in the other direction, with the credit rating dummies capturing some of the liquidity loading.[20] Another potential shortcoming of the transaction-based approach is that the municipal bond in the 1st percentile of liquidity may still be very illiquid relative to Treasuries, which means that the liquidity spread captures relative liquidity in the municipal bond market but not the absolute level of liquidity against the benchmark.

[20] I thank Lorenz Kueng for pointing out this possibility.

To address these concerns, I employ two alternative approaches to decomposing municipal bond spreads. Whereas the transaction-based approach estimates the contribution of liquidity and attributes the remaining spread to default risk, the CDS-based and pre-refunding approaches estimate the contribution of default risk and attribute the residual to liquidity. If these complementary approaches find similar results to the transaction-based approach, then the shortcomings highlighted here are not likely to have a material impact on the decomposition.

D. CDS-Based Approach

The second decomposition approach borrows from the approach to decomposing corporate bond spreads in Longstaff, Mithal, and Neis (2005). Specifically, it uses CDS spreads (or premia) to measure the default component of the tax-adjusted municipal bond spread, or the spread at which the bond would trade in the absence of illiquidity and the tax exemption. The benefit of this approach is that CDS provide a direct measure of credit risk that is less affected by market frictions than the underlying bonds. The downside of this approach is that CDS only reference a subset of state issuers and did not trade prior to 2008.

Longstaff, Mithal, and Neis (2005) use CDS data to decompose corporate bond yield spreads into default and nondefault components. Their simple approach directly compares CDS premia to bond spreads and takes the difference (or basis) as the nondefault component. In a frictionless world, CDS and bond spreads should be exactly the same (notwithstanding some "slippage" due to differences between floating and fixed rate spreads).[21]

However, if it is costlier to trade bonds (e.g., due to search costs) or to hold them in inventory (e.g., due to financing costs), the yield spread on a bond should exceed the corresponding CDS premium. Longstaff, Mithal, and Neis (2005) argue that this should be the case because CDS are contracts in unlimited supply, whereas bonds are securities with limited supply, leading to search costs and value as collateral. Consistent with CDS markets being more liquid than bond markets, Blanco, Brennan, and Marsh (2005) find that credit derivatives markets incorporate new information more quickly than corporate bond markets. Oehmke and Zawadowski (2015) provide a model in which a bond-CDS basis emerges due to the higher cost of trading bonds. Bai and

[21] Longstaff, Mithal, and Neis (2005) use a model-based approach to account for the bias induced by the simple approach. Duffie (1999) shows that, in the absence of frictions, the CDS premium equals the spread between risky and riskless floating-rate bonds. Duffie and Liu (2001) show that the spreads on fixed-rate bonds and floating-rate bonds are not the same. My results compare CDS premia with the spreads on fixed-rate bonds, which induces a slight bias. For my purposes, the simple approach is good enough, as Longstaff, Mithal, and Neis (2005) estimate the fixed-floating bias to be on the order of 5 to 10 bps.

Collin-Dufresne (2013) provide empirical evidence that the basis is large for bonds with higher frictions.[22]

In the corporate market, the CDS premium and bond spread are tied together by arbitrage. No such relation exists between municipal bonds and state CDS, because CDS premium payments are subject to taxation while municipal bond coupons are not. This drives a wedge between the CDS spread (plus the swap rate) and the unadjusted municipal bond yield, similar to the wedge between taxable and tax-exempt bond yields.

The tax treatment of CDS premium payments is currently not defined by regulation. In September 2011, the Treasury proposed that CDS be included in the definition of a Notional Principal Contract, which means premium payments would be treated as income, like taxable bond coupons. However, this remains a proposal, so the tax treatment of CDS is ambiguous. The head of tax at a large hedge fund tells me that most accountants treat CDS as cash-settled put options, with premium payments taxed as capital gains. These premium payments can be interpreted as long-term or short-term in nature, so ultimately the marginal tax rate is between the long-term capital gains rate and the income tax rate. For the purposes of this decomposition, I assume that CDS are taxed at the top statutory income tax rate. If the true marginal tax rate is lower (i.e., the capital gains rate), then the liquidity spread estimates from this approach are biased upward. I discuss this further in Section IV.A.

These issues notwithstanding, application of the CDS-based approach is straightforward. The most liquid CDS contract has a maturity of five years, so I estimate five-year tax-adjusted municipal bond spreads to mitigate maturity effects. Specifically, for each issuer in each month, I estimate a separate regression of individual bond spreads on time to maturity for all bonds in a window of one to nine years to maturity. The five-year tax-adjusted spread is then the fitted value at five years to maturity. After estimating five-year tax-adjusted spreads, the decomposition is simple. The CDS premium is the default spread and the difference (or basis) between the tax-adjusted spread and the CDS premium is the liquidity spread.

E. Pre-Refunding Approach

The third approach to decomposing municipal bond spreads is a quasi-natural experiment that studies changes in spreads around pre-refunding events. Municipal bond issuers commonly pre-refund bonds before the call date by issuing new debt and holding the proceeds in a trust to fund remaining payments until the call date, effectively rendering the pre-refunded bond risk-free (Fischer (1983), Chalmers (1998)). The decision to pre-refund is not random, so the event is not exogenous, but it does provide a clean change from risky to

[22] It is possible that CDS premia include a liquidity component. If this is the case, then the approach in Longstaff, Mithal, and Neis (2005) underestimates the nondefault component of bond spreads. I discuss the robustness of the CDS-based approach in Section III.B.

risk-free for the selected bonds, and I control for bond-specific unobservables using fixed effects.

To estimate the default component of the tax-adjusted spread, I construct a sample of pre-refunded bonds and measure within-bond changes in tax-adjusted spreads around the pre-refunding event. Under the assumptions that the market perfectly incorporates the change in default risk and the liquidity spread does not increase after pre-refunding, this change provides an estimate of the default component of the tax-adjusted spread prior to pre-refunding. If the market underreacts or the liquidity spread increases, then the default spread estimate is biased downward. In particular, Ang, Bhansali, and Xing (2014) point out that liquidity worsens after pre-refunding, which leads to a smaller decline in spreads after pre-refunding relative to a counterfactual where liquidity is unchanged. Thus, the change in spread after pre-refunding should be interpreted as a lower bound on the default spread.

Specifically, I include trades from one year before to one year after the pre-refunding event and regress the tax-adjusted spread on an indicator for whether the bond is pre-refunded:

$$y_{i,t}^{TA} - r_t = \alpha + \beta PreRefunded_{i,t} + Rating_{i,t} + Controls_{i,t} + \delta_i + \delta_t + \epsilon_{i,t}, \quad (10)$$

where *PreRefunded* is an indicator equal to one if the bond has been pre-refunded, *Rating* includes rating category dummies, *Controls* include time to the call date and log issue size, and δ_i and δ_t are bond and month fixed effects. The fixed effects control for bond-specific mispricing and marketwide conditions. The regression coefficient β is the within-bond change in average spread from before to after pre-refunding and is a lower bound on the default component of the tax-adjusted spread. In additional specifications, I consider differential pricing effects for less creditworthy issuers by interacting the pre-refunded dummy with the rating category dummies.

III. Decomposition Results

This section reports the results of the municipal bond spread decomposition. First, I summarize the results of the transaction-based decomposition at the individual bond level and explore the determinants of liquidity and default spreads. Second, I compare the results of the transaction-based and CDS-based approaches at the issuer level. Third, I present the results of the quasi-natural experiment around pre-refunding events. Finally, I interpret the level of default spreads and discuss the high risk premium implicit in these estimates.

A. Transaction-Based Decomposition

Table IV summarizes the results of the transaction-based decomposition. Observations are at the bond-month level, with yields and spreads based on the last fundamental price of the month. For the full sample period covering 1998 to 2015, the average yield is 2.57%, which corresponds to a tax-adjusted

Table IV

Summary Statistics for Transaction-Based Decomposition

This table reports summary statistics for the transaction-based bond spread decomposition. Observations are reported at the bond-month level. *Yield* is yield to maturity. *Tax-Adjusted Yield* is the yield adjusted upward with the top statutory income tax rate as in equation (3). *Tax-Adjusted Spread* is the tax-adjusted yield minus the interpolated maturity-matched swap rate. *Default Spread* and *Liquidity Spread* are the respective components of the tax-adjusted spread resulting from the transaction-based procedure outlined in Section II.C. *Default/Tax-Adj.* is the ratio of the default spread to the tax-adjusted spread.

	Mean	StDev	p_1	p_{10}	p_{50}	p_{90}	p_{99}
Full Sample (38,091 Observations)							
Yield (%)	2.57	1.31	0.42	0.84	2.56	4.27	5.34
Tax-Adjusted Yield (%)	4.32	2.24	0.73	1.45	4.24	7.34	9.41
Tax-Adjusted Spread (bps)	131	83.1	−3.77	40.8	116	241	419
Default Spread (bps)	101	75.8	−29.3	19.2	88.6	198	355
Liquidity Spread (bps)	30.0	27.3	0	5.13	22.4	64.3	129
Default/Tax-Adj.	0.74	0.34	−0.94	0.43	0.81	0.95	2.23
1998 to 2006 (13,047 Observations)							
Yield (%)	3.65	0.91	1.40	2.38	3.68	4.86	5.38
Tax-Adjusted Yield (%)	6.21	1.69	2.29	3.94	6.15	8.56	9.48
Tax-Adjusted Spread (bps)	130	70.1	9.19	46.9	121	223	336
Default Spread (bps)	101	62.9	−17.4	26.4	95.4	184	273
Liquidity Spread (bps)	28.2	28.1	0	4.14	19.6	63.0	136
Default/Tax-Adj.	0.76	0.29	−0.49	0.48	0.83	0.96	1.00
2007 to 2009 (7,141 Observations)							
Yield (%)	3.14	0.87	0.98	1.84	3.30	4.07	4.98
Tax-Adjusted Yield (%)	5.17	1.45	1.60	3.03	5.43	6.72	8.26
Tax-Adjusted Spread (bps)	164	102	−4.97	58.6	138	324	419
Default Spread (bps)	133	93.8	−31.6	32.0	112	277	377
Liquidity Spread (bps)	31.1	28.2	0	4.76	23.6	66.9	135
Default/Tax-Adj.	0.78	0.33	−0.92	0.53	0.85	0.96	2.23
2010 to 2015 (17,903 Observations)							
Yield (%)	1.55	0.85	0.41	0.64	1.35	2.73	4.15
Tax-Adjusted Yield (%)	2.61	1.39	0.71	1.11	2.30	4.54	6.76
Tax-Adjusted Spread (bps)	118	79.8	−4.97	33.0	103	222	413
Default Spread (bps)	87.5	72.4	−34.9	12.3	75.1	178	345
Liquidity Spread (bps)	30.8	26.1	0.48	6.12	24.0	63.9	122
Default/Tax-Adj.	0.70	0.37	−0.94	0.36	0.78	0.93	2.23

yield of 4.32%. The typical bond has a tax-adjusted spread of 131 bps, which breaks down to a default spread of 101 bps and a liquidity spread of 30 bps. The average ratio of the default spread to the tax-adjusted spread is 0.74 and the median is 0.81.[23] Thus, default risk accounts for 74% and liquidity accounts for 26% of the tax-adjusted spread for the average bond.

[23] There are some extreme values reported for the default spread and the ratio of the default spread to tax-adjusted spread. These outliers result from the estimation procedure and are mitigated by winsorizing all variables at the 1% and 99% levels.

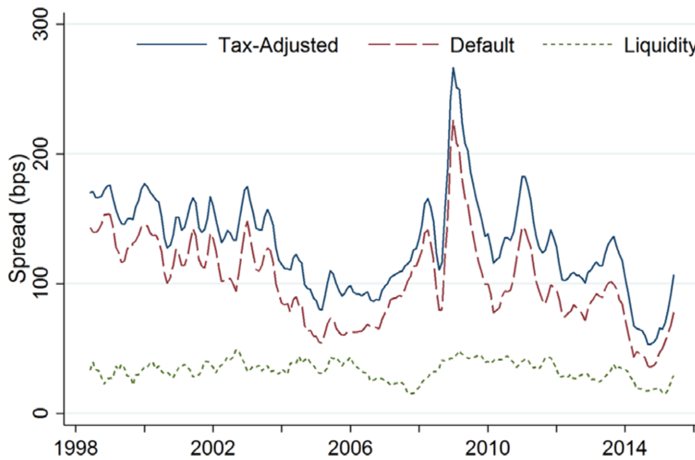

Figure 1. Time series of decomposed bond spreads. This figure presents time-series plots of decomposed bond spreads. Each line presents equal-weighted averages over four-month rolling windows. The solid line is the tax-adjusted spread over the swap rate, the dashed line is the default spread, and the dotted line is the liquidity spread. (Color figure can be viewed at wileyonlinelibrary.com)

The bottom section of Table IV breaks the sample into three subperiods delineated by the financial crisis and the events leading up to it, which included ratings downgrades for the monoline insurers that roiled the municipal bond market. Yields decrease by more than half from the first subperiod to the last subperiod due to declining interest rates, but the tax-adjusted spread is similar at the beginning and end of the sample, averaging 130 bps from 1998 to 2006, 164 bps from 2007 to 2009, and 118 bps from 2010 to 2015. However, the relative contributions of default risk and liquidity change from before to after the crisis, primarily due to variation in the default component. Liquidity spreads are steady throughout the sample, with a small increase during the financial crisis. Default spreads vary more widely, averaging 101 bps from 1998 to 2006, 133 bps from 2007 to 2009, and 87.5 bps from 2010 to 2015.

Figure 1 plots the time series of average tax-adjusted, default, and liquidity spreads. Tax-adjusted spreads are steady from 1998 to 2003, decline substantially from 2003 to 2005, and then spike up dramatically at the beginning of 2008, nearly tripling from the beginning of 2007 to the end of 2008. After the financial crisis, volatility in spreads remains high but the level of spreads declines steadily to the lowest level of the sample period in the third quarter of 2014. Consistent with default risk accounting for most of the spread, the series of default spreads closely tracks the series of tax-adjusted spreads.

Table V presents average bond spreads from 2010 to 2015 for the states, cities, and counties with the highest tax-adjusted spreads. Unsurprisingly, Detroit and Chicago are the two cities with the highest default spreads by a significant margin. Detroit filed for bankruptcy in July 2013 and Novy-Marx and Rauh (2011a) predict that Chicago will not be able to fund its pension obligations

Table V

Select Issuer Bond Spreads, 2010 to 2015

This table reports average monthly estimates of tax-adjusted and default spreads at the five-year horizon from 2010 to 2015 for states, cities, and counties. The top half of the table contains the top 10 states by average tax-adjusted spread, while the bottom half contains the top nine cities and counties by average tax-adjusted spread, plus New York City, which is the most actively traded city or county issuer. The five-year bond spreads are generated by taking individual bond spreads in a window of one to nine years to maturity, regressing these spreads on time to maturity, and taking the fitted value at five years. Only issuers with trading in at least one bond below and one bond above five years to maturity are included in a given month. *Tax-Adj.* is the tax-adjusted spread, equal to the tax-adjusted yield from equation (3) minus the interpolated maturity-matched swap rate. *Default* is the default component of the tax-adjusted spread resulting from the transaction-based approach described in Section II.C. *Def./TA* is the ratio of the default spread to the tax-adjusted spread. *# Bonds* is the average number of bonds in the one to nine years to maturity window in the included months. *N* is the number of months for which fitted tax-adjusted and default spreads are available.

Issuer	Tax-Adj.	Default	Def./TA	# Bonds	*N*
States					
Illinois	231	198	0.86	5.51	54
Oregon	192	121	0.63	3.03	7
California	177	137	0.78	29.6	66
Michigan	168	137	0.82	2.79	6
New Jersey	143	114	0.80	3.91	38
Mississippi	141	114	0.81	2.29	6
New York	139	103	0.74	4.25	33
Hawaii	137	103	0.75	5.42	52
Nevada	128	103	0.80	2.73	22
Florida	127	100	0.79	2.17	6
Cities and Counties					
Detroit, MI	419	361	0.86	2.00	1
Chicago, IL	383	305	0.80	2.00	1
Cook County, IL	221	193	0.87	3.17	12
Nassau County, NY	221	182	0.82	2.70	10
Stamford, CT	206	170	0.83	2.50	2
Clark County, NV	198	157	0.79	2.80	3
San Francisco, CA	194	165	0.85	2.56	7
Suffolk County, NY	192	146	0.76	2.67	9
Cuyahoga County, OH	191	152	0.80	2.00	4
New York, NY	169	132	0.78	17.5	65

from existing assets after 2019. Illinois is the state with the highest default spread, also due to problems with pension funding. Nevertheless, during this period the tax-adjusted spreads for Detroit and Chicago are comparable to the average spread on BB-rated corporate bonds and Illinois's spread is comparable to the average spread on BBB-rated corporate bonds, which are considered investment grade. Thus, even the least creditworthy issuers in my sample are comparable to marginally investment-grade corporate issuers. Interestingly, there is substantial variation across state and local government issuers in the number of bonds traded in the typical month and the number of months for

Table VI

Determinants of Liquidity and Default Spreads

This table reports panel regressions of bond spreads on bond and issuer characteristics. *Tax-Adjusted Spread* is the tax-adjusted yield minus the interpolated maturity-matched swap rate. *Default Spread* and *Liquidity Spread* are the respective components of the tax-adjusted spread resulting from the transaction-based procedure outlined in Section II.C. *Bond Duration* is the bond's duration. *Bond Age* is the number of years since issuance. Log(*Bond Amount Issued*) is the log of the dollar amount in the bond issue. *Issuer Debt/Revenue* is the ratio of debt outstanding to total revenue, reported annually by the U.S. Census Bureau. *State GDP per Capita* is obtained annually from the U.S. Bureau of Economic Analysis. The rating variables are dummies equal to one if the bond is in that rating category. The missing category includes bonds rated BBB or below and nonrated bonds. t-statistics based on standard errors clustered by state and year are reported in brackets. *, **, and *** indicate that the corresponding p-values are less than 0.05, 0.01, and 0.001, respectively.

Dependent Variable:	(1) Tax-Adjusted Spread	(2) Liquidity Spread	(3) Default Spread
Bond Duration	14.4***	4.22***	10.2***
	[14.4]	[8.35]	[12.5]
Bond Age	3.97***	2.13***	1.84***
	[10.6]	[6.04]	[7.99]
Log(Bond Amount Issued)	−2.78	−1.03	−1.75
	[−1.91]	[−1.43]	[−1.42]
Issuer Debt/Revenue	37.1*	4.49	32.6*
	[2.03]	[1.20]	[2.09]
State GDP per Capita ($000s)	−2.14**	−0.19	−1.95**
	[−2.61]	[−0.98]	[−2.75]
AAA-Rated	−107***	−33.2	−74.3***
	[−5.97]	[−1.65]	[−4.62]
AA-Rated	−101***	−30.7	−70.0***
	[−6.53]	[−1.52]	[−4.42]
A-Rated	−12.1	−22.5	10.4
	[−1.06]	[−1.12]	[0.98]
Constant	219***	41.4	177***
	[9.68]	[1.87]	[7.14]
R^2	0.36	0.18	0.29
Observations	19,564	19,564	19,564

which it is possible to calculate a fundamental price during this period. New York City has as many bonds traded as the most active states, while large states like Florida and Michigan have little trading activity.

A.1. Determinants of Liquidity and Default Spreads

Table VI explores the determinants of tax-adjusted, liquidity, and default spreads. It reports regressions of spreads on bond and issuer characteristics, as well as state economic conditions. The explanatory variables in the regressions come from sources other than the transaction data, so these regressions serve as a useful test for the success of the spread decomposition. Spreads are observed at the bond-month level, but issuer characteristics and state economic conditions are observed annually, so I cluster standard errors by state and year to account for correlated errors induced by repeated values of the explanatory variables.

Tax-adjusted spreads are higher for bonds with worse credit ratings, bonds with longer duration, bonds that were issued farther in the past, issuers with higher debt-to-revenue ratios, and states with lower GDP per capita. The term structure of yield spreads is upward-sloping and the creditworthiness of issuers, reflected by balance sheet strength and economic conditions, is an important determinant of borrowing costs.

Columns (2) and (3) of Table VI estimate the same regression for liquidity and default spreads. Since these components sum to the tax-adjusted spread, the coefficients also sum to the coefficients in the tax-adjusted spread regression. Liquidity spreads are exposed to duration and account for the bulk of the loading on time since issuance, consistent with long-maturity bonds and bonds farther from issuance facing higher transaction costs. Somewhat surprisingly, log of amount issued is an insignificant determinant of liquidity spreads.[24] Liquidity spreads are also unexposed to the issuer's creditworthiness or state economic conditions. On the other hand, while default spreads are also exposed to duration and time since issuance, they account for almost all of the spread exposure to the issuer's debt-to-revenue ratio, state GDP per capita, and the bond rating indicators. The Internet Appendix contains a table showing that the coefficients in these regressions are similar in magnitude and only slightly weaker in statistical significance when issuer and month fixed effects are included. These results are consistent with the transaction-based approach successfully separating liquidity and default components of the tax-adjusted spread.

A.2. Closer Look at Liquidity Spreads

In Figure 1, liquidity spreads appear to be fairly steady relative to tax-adjusted and default spreads, in part because of their small relative scale. Figure 2 takes a closer look at the time series of average liquidity spreads. Liquidity spreads are steady from 1998 to 2005, and then they decline rapidly until the end of 2007. This may be related to the improvements in transaction price disclosure made by the MSRB during this period, culminating with real-time transaction reporting in 2005.[25] At the start of 2008, liquidity spreads spike up dramatically, remain elevated until the end of 2012, and then decline again with some volatility, reaching their pre-crisis low in the third quarter of 2014.

To explore the source of this time-series variation in liquidity pricing, Panel B of Figure 2 plots the time series of the normalized liquidity variable λ and

[24] Municipal bonds are often issued in series, with several distinct bonds from the same borrower issued at one time. The Internet Appendix contains a table showing that the ratio of issue size to the size of the series is also insignificant in these regressions.

[25] Schultz (2012) finds that dispersion in primary market transaction prices fell after the introduction of real-time transaction reporting.

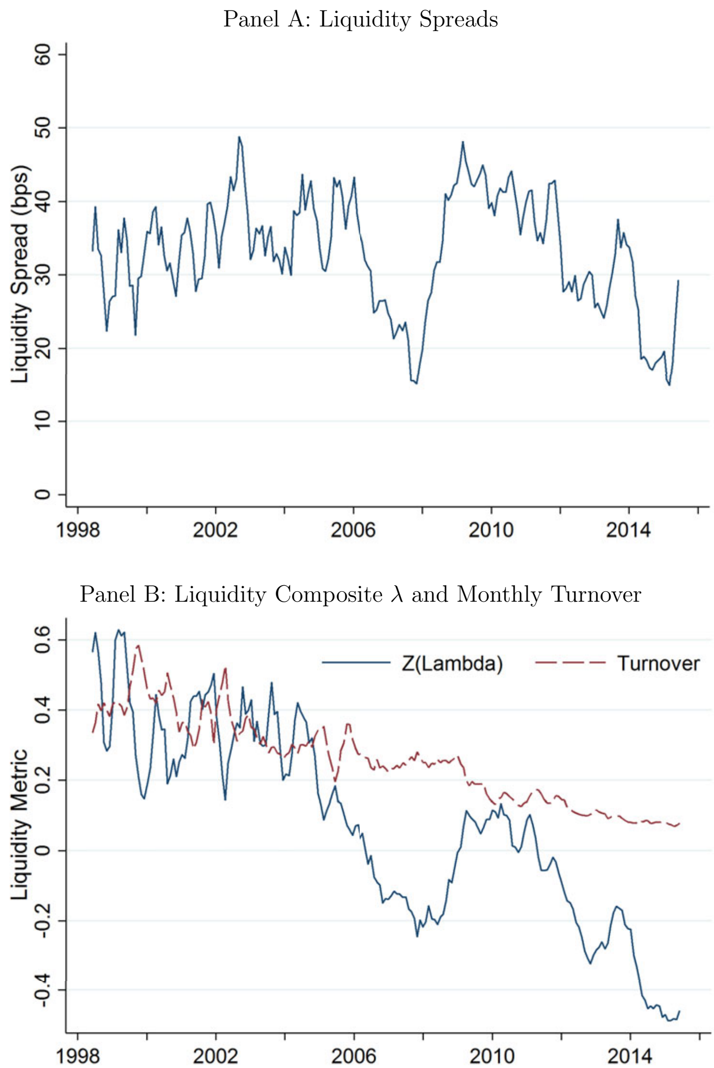

Figure 2. Time series of liquidity spreads and bond liquidity. This figure presents time-series plots of liquidity spreads and measures of bond liquidity. Each line presents equal-weighted averages over four-month rolling windows. Panel A plots the time series of liquidity spreads at a different scale from. Figure 1. Panel B plots the time series of the normalized liquidity composite λ and the monthly rate of turnover. The solid line is normalized λ, which is defined in equation (4) and normalized for scale. The dashed line is monthly turnover, which equals the ratio of par amount traded to par amount issued. (Color figure can be viewed at wileyonlinelibrary.com)

the monthly turnover rate. Turnover declines steadily over the sample period, while the liquidity composite λ declines steadily from 1998 to 2007, spikes at the beginning 2008, and then remains elevated until 2011, when it declines to an all-time low. These plots are consistent with transaction costs and liquidity risk driving the spike in liquidity spreads during the financial crisis, rather than an increase in trading intensity.

The corporate bond market serves as a useful comparison for these municipal bond liquidity spread estimates. From 1998 to 2015, A-rated corporate bond spreads averaged 120 bps over the swap rate, which compares well with the average tax-adjusted spread of 131 bps for the municipal bond sample. Using a similar transaction-based approach, Dick-Nielsen, Feldhutter, and Lando (2012) estimate a liquidity spread of 3 bps for A-rated corporate bonds, which is equal to 11% of the total spread over the swap rate, from the first quarter of 2005 to the first quarter of 2007. From the second quarter of 2007 to the second quarter of 2009, the liquidity spread increases to 51 bps for A-rated corporate bonds, which is equal to 26% of the total spread. During the pre-crisis period, liquidity spreads in the municipal bond market are significantly higher than liquidity spreads for investment-grade corporate bonds, but during the financial crisis, liquidity spreads increase by less for municipal bonds and the level of liquidity spreads is similar for these asset classes.

The difference in normal times is consistent with higher transaction costs in the municipal bond market. Comparing Table II in this paper with Table II in Dick-Nielsen, Feldhutter, and Lando (2012), the median price impact in the municipal bond sample is 7.6 times higher than the median price impact for corporates, while the round-trip cost is 1.4 times higher. Three-quarters of the transactions in the municipal bond sample qualify as retail trades using the $100,000 cutoff proposed by Dick-Nielsen, Feldhutter, and Lando (2012), who exclude trades below this threshold in their analysis.

The difference in the crisis is surprising, but could be attributed to one economic factor and one econometric issue. First, investors in municipal bonds have lower leverage than investors in corporate bonds, because interest payments on debt used to fund tax-exempt bond portfolios are not deductible according to IRS regulations.[26] This may reduce concerns about fire sales in the municipal bond market. Second, it is possible that the transaction-based approach underestimates the role of liquidity in the crisis because it estimates relative liquidity within the municipal bond market, so it might miss a widening of the liquidity gap between the most liquid municipal bond and the swap rate. The CDS-based approach in the next section aims to mitigate concerns with respect to this econometric issue.

B. CDS-Based Decomposition and Comparison of Methods

The transaction-based approach results in a decomposition of municipal bond spreads that attributes 74% of the average tax-adjusted spread to default risk. However, as pointed out in Section II.C and again in the discussion of liquidity

[26] Tender Option Bond (TOB) programs circumvent this regulatory constraint and allow investors to leverage municipal bond portfolios. According to Bergstresser, Cohen, and Shenai (2010), TOB programs disproportionately held insured bonds, which are excluded from my sample, in the run-up to the financial crisis.

Table VII

Comparison of Decomposition Methods

This table reports summary statistics for municipal bond and CDS spreads at a five-year maturity. The sample includes 936 observations for states with nonmissing CDS premia, a subset of the months between 2008 and 2015. The five-year bond spreads are generated by taking individual bond spreads in a window of one to nine years to maturity, regressing these spreads on time to maturity, and taking the fitted value at five years. Only issuers with trading in at least one bond below and one bond above five years to maturity are included in a given month. *Tax-Adjusted Yield* is the yield adjusted upward with the top statutory income tax rate as in equation (3). *Tax-Adjusted Spread* is the tax-adjusted yield minus the interpolated maturity-matched swap rate. *Default Spread* and *Liquidity Spread* are the respective components of the tax-adjusted spread resulting from the transaction-based procedure outlined in Section II.C. *Default/Tax-Adj.* is the ratio of the default spread to the tax-adjusted spread. *CDS Premium* is the quoted five-year credit default swap premium from Bloomberg. *Tax-Adj.-CDS Basis* is the difference between the tax-adjusted spread and the CDS premium. *CDS/Tax-Adj.* is the ratio of the CDS premium to the tax-adjusted spread. *Default-CDS Basis* is the difference between the default spread from the transaction-based approach and the CDS premium.

	Mean	StDev	p_1	p_{10}	p_{50}	p_{90}	p_{99}
Tax-Adjusted Spread (bps)	125	71.9	24.4	57.4	108	238	383
Transaction-Based Approach							
Default Spread (bps)	92.6	67.1	−8.78	31.0	74.4	190	337
Liquidity Spread (bps)	32.4	15.4	5.47	14.9	30.6	52.0	78.8
Default/Tax-Adj.	0.69	0.20	−0.34	0.48	0.74	0.86	0.93
CDS-Based Approach							
CDS Premium (bps)	98.8	67.4	26.0	33.0	81.0	195	307
Tax-Adj.-CDS Basis (bps)	26.3	53.1	−106	−38.8	24.4	89.4	195
CDS/Tax-Adj.	0.84	0.45	0.23	0.35	0.76	1.43	2.59
Default-CDS Basis (bps)	−6.13	53.8	−150	−74.5	−4.20	55.8	149

spreads in Section III.A.2, this approach is associated with two potential shortcomings. First, the sensitivity of the tax-adjusted spread could be biased by measurement error or uncontrolled credit risk. Second, the liquidity spread is measured relative to a very liquid municipal bond, which may be significantly less liquid than the benchmark swap rate.

In this section, I implement the alternative CDS-based approach and compare the results to those of the transaction-based decomposition. The CDS-based approach directly measures the default component of the tax-adjusted spread and treats the remainder as the liquidity component, whereas the transaction-based approach estimates the liquidity component and treats the remainder as the default component. These complementary approaches lead to similar results, improving confidence in the conclusions from the transaction-based approach.

Table VII summarizes the results of the transaction- and CDS-based approaches for the 936 monthly observations from states with nonmissing CDS premia over the period 2008 to 2015. Observations are at the issuer level, with bond-level spread estimates interpolated to the five-year maturity for comparison with CDS premia. The average issuer has a five-year tax-adjusted

Table VIII

Comparison of Decomposition Methods by State

This table reports decomposed bond spreads from the transaction- and CDS-based approaches. Observations are at the issuer-month level for 17 states with at least 20 months of nonmissing bond and CDS spreads. The five-year bond spreads are generated by taking individual bond spreads in a window of one to nine years to maturity, regressing these spreads on time to maturity, and taking the fitted value at five years. Only issuers with trading in at least one bond below and one bond above five years to maturity are included in a given month. *Tax-Adj.* is the tax-adjusted yield minus the interpolated maturity-matched swap rate. *Def.* is the estimated default spread from the transaction-based approach. *Def./TA* is the ratio of the default spread to the tax-adjusted spread. *CDS* is the quoted five-year CDS premium from Bloomberg. *CDS/TA* is the ratio of the CDS premium to the tax-adjusted spread. *Def./CDS* is the ratio of the transaction-based default spread to the CDS premium. Ratios denoted with asterisks are significantly different from one based on a test of the difference between the respective spreads. *N* denotes the number of monthly observations. The average of state averages for each variable is reported in the bottom row, with statistical tests based on pooling monthly observations and clustering standard errors by state. *, **, and *** indicate that the corresponding *p*-values are less than 0.05, 0.01, and 0.001, respectively.

		Trans.-Based		CDS-Based			
	Tax-Adj.	Def.	Def./TA	CDS	CDS/TA	Def./CDS	*N*
California	192	153	0.79***	161	0.84***	0.95	89
Connecticut	104	72.4	0.69***	109	1.04	0.67***	59
Delaware	73.0	47.0	0.64***	48.5	0.66**	0.97	28
Illinois	267	229	0.86***	196	0.74***	1.17**	63
Maryland	69.0	41.8	0.61***	65.6	0.95	0.64***	55
Massachusetts	108	73.8	0.69***	93.1	0.87*	0.79**	82
Minnesota	89.4	60.2	0.67***	56.8	0.64***	1.06	52
Nevada	135	107	0.79***	104	0.77**	1.03	24
New Jersey	152	118	0.77***	140	0.92	0.84*	44
New York	140	98.5	0.70***	108	0.77**	0.91	49
North Carolina	81.4	55.8	0.69***	53.1	0.65***	1.05	51
Ohio	118	86.4	0.73***	98.4	0.84**	0.88	74
Pennsylvania	104	71.2	0.68***	90.6	0.87*	0.79**	55
Texas	98.4	66.6	0.68***	66.2	0.67***	1.01	65
Utah	82.0	49.3	0.60***	50.5	0.62***	0.98	21
Washington	99.3	70.7	0.71***	61.2	0.62***	1.16*	43
Wisconsin	97.2	70.1	0.72***	61.5	0.63***	1.14	50
Average	118	86.5	0.73***	92.0	0.78***	0.94	904

spread of 125 bps. The transaction-based approach attributes 69% of the spread to default risk, while the CDS-based approach attributes 84% of the spread to default risk. The CDS premium is 6 bps higher on average than the default spread from the transaction-based approach, but this difference is economically as well as statistically insignificant ($t = 1.47$ with errors clustered by state).

Table VIII compares the transaction- and CDS-based approaches for 17 individual states with at least 20 monthly observations with nonmissing bond and CDS data. Under the transaction-based approach, the contribution of default risk to the bond spread ranges from 60% to 86%, while

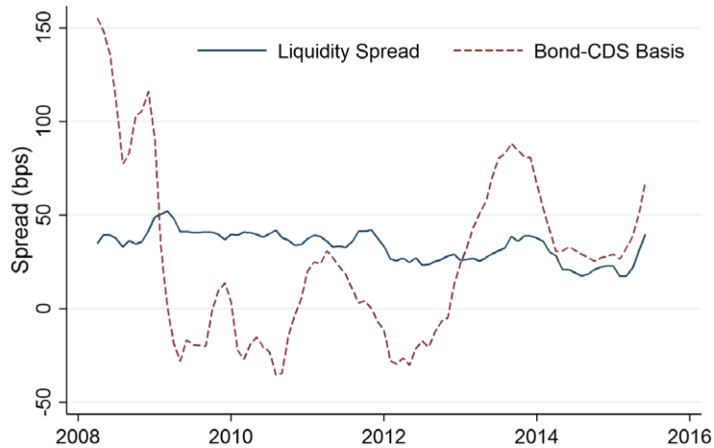

Figure 3. Liquidity spreads and bond-CDS basis. This figure presents time-series plots of liquidity spreads from the transaction-based and CDS-based approaches. The sample is restricted to states with nonmissing CDS premia, a subset of the months between 2008 and 2015. Each line presents equal-weighted averages over four-month rolling windows. The solid line is the estimated liquidity spread from the transaction-based approach. The dashed line is the bond-CDS basis, or the difference between the tax-adjusted spread and the CDS premium, which represents the liquidity spread from the CDS-based approach. (Color figure can be viewed at wileyonlinelibrary.com)

under the CDS-based approach, it ranges from 62% to 104%. The liquidity spread from the transaction-based approach is statistically significant at the 0.1% level for all states, while the bond-CDS basis is significant at the 5% level for all but three states. The levels of default spreads and CDS premia are remarkably similar for individual states, with the difference under 10% of the CDS premium for eight states and under 20% for 14 out of 17 states. For 10 out of 17 states and for the pooled sample, the difference between the default spread and the CDS premium is statistically insignificant, consistent with the two approaches leading to a similar decomposition.[27]

Figure 3 plots the average liquidity spread from the transaction-based approach and the average bond-CDS basis, which is the liquidity spread under the CDS-based approach. During the financial crisis and its aftermath, the bond-CDS basis is between 50 bps and 100 bps higher than the liquidity spread, which validates concerns about the relative nature of the transaction-based approach. After the crisis, the bond-CDS basis declines to zero and is negative in some months, rising above the liquidity spread at the end of 2013 and settling close to it in 2014. The bond-CDS basis is much more volatile than the liquidity spread, which arises from both the estimation of the liquidity spread and the fact that the usual bond-CDS arbitrage does not hold in the tax-exempt

[27] This is a conservative estimate of the number of states with insignificant differences between default spreads and CDS premia. The statistical tests in the Def./CDS column are biased toward rejection because they do not account for estimation error in default spreads from the transaction-based approach.

bond market, allowing for deviations between CDS premia and the underlying bond spreads. Nevertheless, the average level of the spreads is quite similar. If anything, the CDS-based approach implies an even larger role for default risk than the transaction-based approach.

One possible concern with the CDS-based analysis is that liquidity affects CDS premium quotes in the same way it affects municipal bond prices. CDS are contracts rather than securities, so liquidity has a different meaning than it does for bonds in limited supply, but intermediation frictions can affect pricing. Siriwardane (2015) shows that 11% of the variation in corporate CDS premia from 2010 to 2014 can be explained by changes in the capital of the top five protection sellers. However, even attributing 11% of the average state CDS premium to liquidity, the average contribution of default risk to the tax-adjusted spread would be 75% under the CDS-based approach. Thus, allowing for CDS liquidity would actually improve the match between the transaction- and CDS-based decomposition results, because the CDS premium would be less likely to overshoot the default spread.

C. Pre-Refunded Bonds

This section presents the results of a quasi-natural experiment that exploits pre-refunding, an event that renders a bond risk-free until its call date, to place a lower bound on the default spread for a subset of my sample. I construct a sample of pre-refunded bonds starting with all GO bonds from the states and local governments in my sample for which I can identify the refunding bond and its issue date in Bloomberg, which indicates when the original bond became pre-refunded.[28] This starting sample contains 16,982 monthly fundamental prices for 7,573 distinct bonds. All trades occur before the first call date for their respective issues, consistent with the remark in Ang, Bhansali, and Xing (2014) that the refunded bond's maturity is usually the first call date of the original bond. I focus on differences in yield-to-call before and after pre-refunding, so I restrict the sample to bonds with trades observed both before and after the pre-refunding date. This reduces the sample to 5,292 monthly prices for 1,305 bonds. I use differences in credit quality as a determinant of the drop in yield after pre-refunding, so I exclude bonds without a credit rating at issuance, which results in the exclusion of nine observations for two bonds. Finally, I exclude bonds with less than six months to the first call date, because at short maturities, small changes in price result in large changes in yield. The final pre-refunded bond sample includes 4,636 monthly observations for 1,302 bonds.

Panel A of Table IX summarizes the pre-refunded bond sample. The average trade after pre-refunding occurs with 2.46 years to the first call date, while just over 10% of trades have more than five years to the call date.[29] The average

[28] Note that the preceding analysis excludes callable bonds, whereas the pre-refunded sample is based on the same set of issuers but contains callable bonds that are pre-refunded during the sample period.

[29] This contrasts with Ang, Bhansali, and Xing (2014), who report that 27% of trades occur with more than five years to the call date in their pre-refunded sample.

Table IX

Pre-Refunded Bonds

This table reports statistics and regressions on pre-refunded bonds. Panel A reports summary statistics. *Years to Call* is the number of years from the trade date to the first call date. *Tax-Adjusted Spread* is the difference between the tax-adjusted yield-to-call and the interpolated maturity-matched swap rate. Rows labeled $m > -12$ and $m < 12$ include only trades within 12 months of the pre-refunding month. Panel B reports regressions of tax-adjusted spreads within 12 months of pre-refunding on an indicator for whether the bond is pre-refunded and control variables. *Pre-Refunded* is a dummy equal to one if the trade occurs after pre-refunding. *Pre-Refunded*AA* and *Pre-Refunded*A* are interactions of *Pre-Refunded* and indicators for whether the bond is rated AA or A. The omitted category is AAA-rated bonds. *Rating Category* includes rating category dummies. *Bond Controls* include years to call and log issue amount. t-statistics based on standard errors clustered by bond and month are in brackets. *, **, and *** indicate that the corresponding p-values are less than 0.05, 0.01, and 0.001, respectively.

Panel A: Summary Statistics

	Mean	StDev	$p10$	$p50$	$p90$	Obs.
Before Pre-Refunding						
Years to Call	4.06	2.28	1.60	3.40	7.63	2,004
Tax-Adjusted Spread (bps)	222	138	75.1	196	398	2,004
Tax-Adjusted Spread (bps) ($m < 12$)	211	133	69.2	186	384	1,462
Tax-Adj. Spread (bps) (A-Rated, $m < 12$)	245	139	102	217	406	48
After Pre-Refunding						
Years to Call	2.46	1.83	0.71	1.82	5.26	2,632
Tax-Adjusted Spread (bps)	98.3	95.6	15.7	85.4	200	2,632
Tax-Adjusted Spread (bps) ($m < 12$)	103	84.1	26.8	90.6	196	1,016
Tax-Adj. Spread (bps) (A-Rated, $m < 12$)	105	76.4	45.2	86.5	202	23

Panel B: Regressions

Tax-Adj. Spread	(1)	(2)	(3)	(4)	(5)	(6)
Pre-Refunded	−107***	−83.6***	−86.5***	−111***	−87.2***	−95.9***
	[−14.7]	[−8.51]	[−8.99]	[−12.6]	[−7.80]	[−9.17]
Pre-Refunded*AA				11.3	11.3	23.1*
				[1.22]	[1.01]	[2.56]
Pre-Refunded*A				−59.6*	−114**	−122***
				[−2.06]	[−3.23]	[−4.82]
Rating Category	X	X	X	X	X	X
Bond Controls	X	X	X	X	X	X
Bond FEs		X	X		X	X
Month FEs			X			X
R^2	0.19	0.64	0.74	0.19	0.64	0.75
Observations	2,436	2,436	2,436	2,436	2,436	2,436

bond has a tax-adjusted spread of 211 bps in the year prior to pre-refunding and 103 bps in the year after pre-refunding, consistent with pre-refunding reducing default risk.

Panel B of Table IX reports estimates of the regression in equation (10). The decline in tax-adjusted spreads after pre-refunding is 86.5 bps, or 41% of the average tax-adjusted spread prior to pre-refunding, controlling for bond and month fixed effects. The effect of pre-refunding is stronger for riskier A-rated bonds, reducing spreads by 218 bps, or 89% of the average spread prior to pre-refunding, controlling for bond and month fixed effects. This lines up closely with the results from the transaction-based approach in Section III.A.

These estimates imply that, prior to the pre-refunding event, default risk accounts for at least 41% of the tax-adjusted municipal bond spread, assuming the market fully incorporates the reduction in risk and the liquidity spread does not increase after pre-refunding. If the market underreacts or the liquidity spread increases, then these estimates of the default component are biased downward. Thus, the estimates from the pre-refunding regressions should be interpreted as lower bounds on the contribution of default risk to the tax-adjusted spread.[30]

These results conflict with Ang, Bhansali, and Xing (2014), who also rely on pre-refunded bonds for identification and find that default risk accounts for 26% of the tax-adjusted spread. Taken at face value, their result implies that the tax-adjusted spread should decline by less than 26% after pre-refunding. The key difference between my within-bond analysis and the approach in Ang, Bhansali, and Xing (2014) is that they use separate pools of bonds that have and have not been pre-refunded, which could allow differences in issuer characteristics or bond-specific mispricing to contaminate the pre-refunded yield curve.

D. Interpretation of Default Spreads

The results presented in the previous sections from the transaction-based, CDS-based, and pre-refunding approaches all suggest that there is a substantial default component in tax-adjusted municipal bond spreads. The default spread ranges in magnitude from 86.5 bps under the pre-refunding approach to 101 bps under the transaction-based approach. In contrast, Ang, Bhansali, and Xing (2014) find the default component to be 45.4 bps.

Historically, municipal defaults are extremely rare. According to Moody's, from 1970 to 2014 the five-year cumulative default rate for all rated municipal bonds is 0.08%, while for GO bonds the default rate is 0.01%. Based on these historical default rates, the default spreads estimated in the previous sections imply a high premium for default risk in the municipal bond market.

To quantify the default risk premium implied by municipal bond default spreads, I estimate the ratio of the risk-neutral default probability to the physical default probability, in the spirit of Berndt et al. (2005). A simple model of

[30] Two other factors could bias the coefficient estimate downward. First, it would be more appropriate to use the option-adjusted spread prior to the pre-refunding announcement, when there is still uncertainty as to whether the bond will be called. Option-adjusted spreads exceed spreads to call for bonds trading at a premium, which means a larger drop in spread after pre-refunding. Second, the event date is defined as the issuance date of the pre-refunding bond, but the announcement date is often earlier. To the extent that bonds are misclassified as non-pre-refunded when they are expected to be pre-refunded, the spreads in the pre-event period are biased downward.

Table X
Implied Default Risk Premium

This table reports estimates of implied default risk premium multiples based on the default spread estimates in the previous tables. *Default Spread* is the average or baseline specification for each approach based on the full sample. *ABX (2014)* reports the average default spread for the period 1996 to 2013 from Ang, Bhansali, and Xing (2014). The following formula is used to compute the risk-neutral default probability: $\gamma = q * LGD$, where γ is the default spread, q is the risk-neutral default probability, and LGD is the expected loss given default. Three scenarios are considered for loss given default, two based on outcomes from recent municipal bankruptcies and one extreme scenario. The risk-neutral to physical default probability ratio q/p is a multiple reflecting the default risk premium (Berndt et al. (2005)). The physical default probability is assumed to be 0.016%, the annualized default rate for rated municipal bonds, based on the 0.08% historical five-year cumulative default rate for 1970 to 2014 reported by Moody's.

		LGD = 50%		LGD = 80%		LGD = 100%	
Method	Default Spread	q	q/p	q	q/p	q	q/p
Transaction	101 bps	2.02%	126	1.26%	78.8	1.01%	63.1
CDS	98.8 bps	1.98%	124	1.24%	77.5	0.99%	61.8
Pre-Refunding	86.5 bps	1.73%	108	1.08%	67.5	0.87%	54.1
ABX (2014)	45.4 bps	0.91%	56.9	0.56%	35.0	0.45%	28.4

CDS spreads allows me to back out risk-neutral default probabilities from the default spread estimates. Assume that the annual default intensity is constant and that premium payments and default can occur only at the end of each year. Then a binomial tree calculation of the CDS spread leads to the following relation: $\gamma = q * LGD$, where γ is the CDS spread, q is the annual risk-neutral default probability, and LGD is the risk-neutral expected loss given default.

Table X reports implied risk-neutral default probabilities and default risk premium multiples for three LGD scenarios. Bondholder losses were approximately 50% in the recent bankruptcies in Jefferson County, AL, Stockton, CA, and Vallejo, CA, while they were 75% and 82% in the Detroit, MI and San Berndardino, CA bankruptcies, respectively. Zero recovery (LGD = 100%) is the most conservative scenario. I assume that the annualized physical default probability for the typical municipal bond is 0.016%, based on the historical five-year cumulative default rate of 0.08% for all municipal bonds from 1970 to 2014 as reported by Moody's. This is a conservative estimate of the historical default probability because my sample consists of GO issuers, which default at a lower rate of 0.01% over five years.

Under the 50% LGD scenario, the implied annual risk-neutral probability of default is between 1.73% and 2.02%, which is 108 to 126 times higher than the physical default probability. Under the 100% LGD scenario, the risk-neutral default probability is between 0.87% and 1.01%, which is 54 to 63 times higher than the physical default probability. Even the low default spread estimate from Ang, Bhansali, and Xing (2014) leads to a default risk premium multiple between 28 and 57. The interpretation of the 50% LGD scenario is that investors receive between 108 bps and 126 bps of compensation per 1 bp of expected default loss.

To put these figures in the context of the corporate bond market, from 1998 to 2015 AA-rated bonds have an average spread of 86 bps while A-rated bond spreads average 120 bps. Making the same calculation as in Table X with 50% LGD, the risk-neutral default probability is 1.72% for AA-rated bonds and 2.40% for A-rated bonds. The historical five-year cumulative default rate is 0.40% for AA-rated corporates and 0.95% for A-rated corporates, implying annual default probabilities of 0.08% and 0.19%, respectively. This implies risk premium multiples of 21.5 for AA-rated corporates and 12.6 for A-rated corporates.[31] Thus, the default risk premium implied by municipal bond spreads is an order of magnitude larger than the risk premium for investment-grade corporate bonds.

The economic source of this high risk premium is not obvious and merits exploration in future research. The supply of risk-bearing capital relative to the demand for this capital must be lower in the municipal bond market than it is in the corporate market. One source of this difference could be the tax-exempt status of municipal bonds, which discourages institutional investors from participating in the market. Tax exemption also induces market segmentation by state (Pirinsky and Wang (2011), Schultz (2012), Babina et al. (2015)), which could lead to imperfect diversification that increases the return required by risk-averse investors. Another possibility is that large municipal issuers default only in very bad states of the world in which marginal utility is extremely high, but this reasoning applies to investment-grade corporate issuers as well.

IV. Robustness

This section discusses the robustness of the conclusions in the previous sections. First, I compare the simple tax adjustment to alternative tax adjustments based on Green (1993) and Longstaff (2011). Second, I examine the robustness of the results to sample and benchmark selection.

A. Alternative Tax Adjustment

The tax adjustment employed in the spread decomposition has the benefit of being simple, but it is probably not the correct model to map from tax-exempt to taxable yields. For instance, it implies that the tax-exempt and taxable yield curves are parallel and is inconsistent with the extensive literature

[31] Berndt et al. (2005) estimate that the median risk premium multiple is 2.5 for AA-rated corporate bonds and 3.0 for A-rated corporate bonds from 2001 to 2015, assuming 60% LGD. They use Moody's expected default frequencies (EDFs) for individual firms instead of historical default probabilities for the entire rating category. Their use of forward-looking micro data instead of backward-looking aggregate data may be the cause of my lower premium estimates for corporates, along with the possibility that physical default rates are higher from 1998 to 2015 than they were from 1970 to 1997. I thank Antje Berndt for providing updated calculations from Berndt et al. (2005).

on the "muni puzzle," which finds that the tax-exempt curve is steeper than the taxable curve (Green (1993), Chalmers (1998)). It also assumes that the marginal tax rate is constant, in contrast to evidence of a cyclical marginal tax rate in Longstaff (2011). In this section, I discuss two alternative tax adjustments that address these shortcomings of the simple tax adjustment. In the Internet Appendix, I report results based on the alternative tax adjustments that are quantitatively similar to the results presented in this paper.

The first alternative tax adjustment is derived from Green (1993), whose model accounts for the different slopes of the tax-exempt and taxable yield curves. Green's (1993) model of the tax-exempt yield curve is based on the differential taxation of coupon payments and market discount bonds. The Internet Appendix explains how to compute a tax adjustment factor to adjust the tax-exempt spread in the same manner as equation (3) following Green (1993). This alternative tax adjustment results in a similar tax adjustment at short maturities but a smaller tax adjustment at long maturities, especially for the 2% of bond-month observations with over 10 years to maturity, for which coupon payments are a larger proportion of the total cash flow. Under the Green (1993) adjustment, these long maturities have lower tax-adjusted spreads relative to the simple tax adjustment. However, the contribution of default risk to the tax-adjusted spread is similar under the transaction-based approach, with a difference under 5% even at maturities over 10 years. The CDS-based approach results in a 1% higher ratio of the CDS premium to the tax-adjusted spread and a smaller bond-CDS basis, due to lower tax-adjusted spreads, but this effect is economically negligible. Overall, the Internet Appendix results on the Green (1993) tax adjustment suggest that the spread decomposition and the conclusions on default risk are robust to the method of adjusting for taxation.

The second alternative tax adjustment uses estimates from Longstaff (2011), who identifies the marginal tax rate with data on short-term municipal swaps from 2001 to 2009. His estimates of the marginal tax rate are close to the top statutory rate in the early 2000s, increase to nearly 50% in 2007, and then become more volatile, ranging from 55% in September 2008 to 8% in February 2009. I apply the simple tax adjustment with Longstaff's (2011) estimates as the federal tax rate and the top statutory rate as the state tax rate. The results in the Internet Appendix are consistent with those in the paper, with some large differences in the level of spreads but a similar decomposition into default and liquidity components.

In general, the application of a lower marginal tax rate in equation (3) results in lower tax-adjusted spreads. This has an ambiguous effect on the transaction-based approach, but reduces the bond-CDS basis and increases the contribution of default risk to the tax-adjusted spread under the CDS-based approach. Kueng (2015) estimates that the marginal tax rates implied by short-maturity bonds are below the top statutory rate and that the rates implied by longer-maturity bonds are even lower. In that case, my simple tax adjustment can be viewed as conservative with respect to the conclusions on default risk from the CDS-based approach, because a smaller tax adjustment would result in an even smaller role for liquidity.

B. Alternative Samples and Benchmark

Several choices were made in constructing the sample for this analysis that are detailed in Panel A of Table I. The Internet Appendix includes tables replicating the main results for alternative sample constructions. The results are quantitatively similar when callable bonds are included in the sample, when insured bonds are included, when market discount trades are excluded, when the sample is restricted to state bonds, and when the sample is restricted to interdealer trades.

The benchmark risk-free rate used throughout the analysis is the swap rate. Swap rates are typically between 20 bps and 50 bps higher than Treasury rates, due to illiquidity and a small amount of credit risk. The Internet Appendix includes tables showing that the main results are similar when the off-the-run Treasury curve is the risk-free benchmark (Gurkaynak, Sack, and Wright (2007)). The results of the transaction- and CDS-based approaches differ slightly because the swap-Treasury basis drives part of the bond-CDS basis when bond spreads are based on the Treasury curve, but the main conclusions of the decomposition are the same.

V. Conclusion

This paper contributes to our understanding of municipal bond pricing by showing that default risk accounts for most of the municipal bond spread, while liquidity plays a secondary role. Given the rare incidence of default in this market, it is surprising that default risk is the primary driver of yield spreads. The implied risk premium is an order of magnitude larger than the default risk premium in the corporate bond market, likely due to market frictions limiting the supply of risk-bearing capital.

In contrast with the extensive literature on transaction costs in the municipal bond market, I find that liquidity is not a key driver of municipal bond yields. This follows intuitively from the liquidity discount depending on both the expected cost of trading and the expected trading intensity, or need to sell the bond. The typical municipal bond investor is a buy-and-hold retail investor, so trading intensity is low, leading to a low liquidity spread.

The municipal bond risk premium uncovered by this paper merits exploration in future research. Two potential channels related to the tax exemption could drive this premium. First, the tax exemption discourages institutional investors, who have low or even zero marginal income tax rates, from investing in the market, which limits the supply of risk-bearing capital. Second, the tax exemption induces market segmentation across states, leading to imperfect diversification that could allow retail investor risk-aversion to raise yields. Related to this, Babina et al. (2015) show that bonds from states with higher tax rates have more home-biased ownership and greater susceptibility to idiosyncratic risk.

The results in this paper and the questions they raise have important policy implications. If lowering state and local government borrowing costs is a policy objective, then my results imply that focusing on improving liquidity in the municipal bond market will have a smaller effect than focusing on the source of the default risk premium. If the tax exemption is the source of this premium, then it would be worth examining alternative schemes for the federal government to subsidize state and local issuers without inducing market segmentation.

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Appendix A: Variable Definitions

A. Amihud Measure

Amihud (2002) constructs a measure of price impact, or the market depth dimension of liquidity. Whereas Amihud (2002) uses daily stock prices and volumes to estimate his liquidity measure, I have transaction data for municipal bonds, so I can estimate a finer measure of trade-by-trade price impact. I estimate the modified Amihud measure for each day as follows:

$$Amihud_{i,t} = \frac{1}{N_t}\sum_{j=1}^{N_t}\frac{|r_j|}{Q_j} = \frac{1}{N_t}\sum_{j=1}^{N_t}\frac{\left|\frac{P_j - P_{j-1}}{P_{j-1}}\right|}{Q_j}, \tag{A1}$$

where N_t is the number of trades on day t, P_j is the price of the bond at trade j, and Q_j is the par amount of trade j. I require at least two transactions on a given day to estimate the Amihud measure. Monthly estimates of the Amihud measure are obtained by taking the median of the daily estimates in a month.

B. Imputed Round-Trip Cost

Feldhutter (2012) proposes a measure of liquidity based on the institutional setting of the over-the-counter bond market. Roundtrip trades are groups of transactions in a bond where a dealer matches a buyer with a seller, so in a short span of time there is a purchase from a customer, a sale to a customer, and possibly an interdealer trade, if a second dealer is involved in the matching. If two or three trades occur in a given bond with the same trade size on the same day, this is called an imputed round-trip trade, the cost of which is given by

$$IRC_{i,t} = \frac{P_{\max} - P_{\min}}{P_{\min}}, \tag{A2}$$

where $P_{\max}$ is the highest price and $P_{\min}$ is the lowest price in the imputed round-trip trade. Higher values of the imputed round-trip cost imply higher transaction costs. Monthly estimates of the imputed round-trip cost are obtained by taking the mean of the daily estimates in a month.

C. Price Dispersion

Jankowitsch, Nashikkar, and Subrahmanyam (2011) develop an alternative measure of transaction costs that is based on the dispersion of traded prices around the market "consensus valuation." This measure is similar to the imputed round-trip cost but is not perfectly correlated, so I employ them both here. The daily price dispersion measure is defined as

$$Dispersion_{i,t} = \sqrt{\frac{1}{\sum_{j=1}^{N_t} Q_j} \sum_{j=1}^{N_t} (P_j - M_t)^2 Q_j}, \tag{A3}$$

where N_t is the number of trades on day t, P_j is the price of the bond at trade j, Q_j is the par amount of trade j, and M_t is the market "consensus valuation," which I define as the daily volume-weighted average price of the bond. I use a different definition of the fundamental price of a bond here than in the rest of the paper because this way I can calculate price dispersion even on days when there is neither a sale and purchase pair nor an interdealer trade. Monthly estimates of the price dispersion measure are obtained by taking the mean of the daily estimates in a month.

D. Roll Measure

Roll (1984) shows that successive asset returns will have negative autocorrelation when there is a bid-ask spread in the market for the asset. He shows that the effective bid-ask spread can be measured by

$$Roll_{i,t} = 2\sqrt{-\mathrm{Cov}(\Delta \mathrm{P_j}, \Delta \mathrm{P_{j-1}})}, \tag{A4}$$

where P_j is the price at trade j and the measure is set to zero when the covariance between successive price movements is positive. The Roll measure is higher when the effective bid-ask spread is higher, because the "bid-ask bounce" that occurs between successive transactions leads to more negative autocovariance in price changes. I estimate the Roll measure on each day there is at least one trade, using a trailing 30-day window. I discard estimates for which at least four trades do not occur in the window. Due to this requirement, the Roll measure is missing for many more observations than the other liquidity measures used in this paper. Monthly estimates of the Roll measure are obtained by taking the median of the daily estimates in a month.

E. Trading Activity Variables

The trading activity variables used in this paper include turnover, trades per month, trading interval, and issuer zero-trade days. Turnover is the ratio of monthly trading volume to the bond's amount outstanding. Trades per month is simply the number of trades occurring in a given month. On a daily basis, trading interval is the number of days since the previous trade. Monthly estimates of trading interval are obtained by averaging the daily estimates in a month. Issuer zero-trade days are the proportion of days in a month during which none of the issuer's bonds trade.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1: Internet Appendix.